Water Resources Center
Annual Technical Report
FY 2010

Introduction

The Minnesota WRRI program is a component of the University of Minnesota's Water Resources Center (WRC). The WRC is a collaborative enterprise involving several colleges across the University, including the College of Food, Agriculture and Natural Resource Sciences (CFANS), the University of Minnesota Extension, Minnesota Agricultural Experiment Station (MAES) and the University of Minnesota Graduate School. The WRC reports to the Dean of CFANS. In addition to its research and outreach programs, the WRC is also home to the Water Resources Sciences graduate major which offers both MS and PhD degrees. The WRC has two co-directors, Professor Deborah Swackhamer and Faye Sleeper, who share the activities and responsibilities of administering its programs.

Research Program Introduction

The WRC funds 3-4 research projects each year, and the summaries of the current projects are found in the rest of this report.

Reductive degradation of pesticides: Solid-state and solution-phase dynamics

Basic Information

Title:	Reductive degradation of pesticides: Solid-state and solution-phase dynamics
Project Number:	2009MN246B
Start Date:	3/1/2009
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	MN 05
Research Category:	Water Quality
Focus Category:	Toxic Substances, Geochemical Processes, Non Point Pollution
Descriptors:	
Principal Investigators:	William Alan Arnold, R. Lee Penn

Publications

1. Moore, K., B. Forsberg, D. R. Baer, W. A. Arnold, and R. L. Penn. 2011. Zero Valent Iron: Impact of Anions Present During Synthesis on Subsequent Nanoparticle Reactivity. Journal of Environmental Engineering, accepted.
2. Penn, R.L., K. Moore, T. A. Do, and W. A. Arnold. Impact of Aggregation State on the Evolving Reactivity of Iron Oxide Nanoparticles. American Chemical Society 241st National Meeting, Anaheim, CA, March 31, 2010.
3. Arnold, W.A., R. L. Penn, K. Moore, A. Do, and A. M. Stemig. Unexpected Changes in Aggregation and Mineralogy of Goethite During the Reduction of Nitroaromatics. Goldschmidt 2011, Prague, Czech Republich, August 14-19, 2011.

Reductive degradation of pesticides: Solid-state and solution-phase dynamics

Principal Investigators
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R. Lee Penn, Associate Professor, Department of Chemistry, University of Minnesota;

Funding Source: USGS-WRRI 104B/ CAIWQ Competitive Grants Program

Project Duration: 3/1/09 - 2/28/11
Reporting Period: 3/1/10-2/28/11

Summary

Every year, thousands of pounds of pesticides are used on Minnesota's farmland. After application these pesticides can leach into groundwater used as drinking water resources. Some of these pesticides can undergo abiotic reductive degradation. Degradation of the pesticides occurs at the mineral-water interface, and over time the reactivity of the mineral surfaces changes. These changes can affect the reactivity of the particles. The project objective was to quantify changes in the mineralogy of iron sediments resulting from abiotic degradation of pesticides and to link these changes with the degradation kinetics of the pesticides. Results will make it possible to determine the ability of sediment to degrade pesticides with long term exposure. The pesticides investigated were trifluralin and mesotrione, both of which are nitroaromatic herbicides. Both pesticides also potentially degrade by reductive degradation. Trifluralin is a pre-emergence herbicide, while mesotrione is a pre and post-emergence herbicide. Both pesticides are used for control of grass and broadleaf weeds.

Research

The objective of this study was to quantitatively characterize changes in goethite properties as a function of repeated exposure to Fe(II) and trifluralin and mesotrione and to link those changes with the evolving reactivity of the system. This was done through kinetic batch experiments in which the each herbicide was added to an Fe(II)/goethite suspension. Sequential spike experiments, in which the herbicide concentration was restored to its initial value were also performed. All pre- and post- reaction materials were characterized using x-ray diffraction (XRD) and transmission electron microscopy (TEM). Reactions were also performed with a goethite containing sand to compare the reactivity to goethite. The goal was to compare the kinetic results with changes observed in the solid-state materials to elucidate the link between solid-state changes and changes in reaction rates.

Experiments are carried out under anaerobic conditions. MOPS buffer solutions of pH 7.5 and concentration of 25 mM were prepared using ultrapure water deoxygenated by purging with nitrogen. The buffer solutions were prepared in an anaerobic glovebag. Reactions were carried out in 124 mL serum bottles containing goethite and buffer solution. Enough buffer solution was added to ensure no headspace was present in the reactors. Ferrous iron was added to the reactors in the form of an acidified ferrous chloride solution at a concentration of 1.0 mM. The reactors sat overnight in the glovebag to allow for equilibration.

To initiate reactions methanolic pesticide stock solutions were spiked in at determined concentrations. The reactors were then placed on rotators. Samples were periodically withdrawn and a 1:1 volume extraction with hexane was performed when trifluralin was the target molecule. Samples were filtered into a solution of hydroxylamine hydrochloride when mesotrione was the target. The samples were then analyzed using either GC/MS (trifluralin) or HPLC (mesotrione). When the pesticide was no longer detected the reactor was respiked with ferrous chloride to return the ferrous iron concentration to 1 mM. The reactor was again allowed to equilibrate and then the pesticide stock solution was respiked into the reactor. This process was repeated multiple times. The concentration of ferrous chloride in the reactor was measured after each reaction using the ferrozine method. Rate constants were calculated using the GC/MS and HPLC data for each spike.

Samples of the goethite suspension were taken after each reaction for TEM analysis. Each sample was centrifuged using an Eppendorf 5415 centrifuge at 2320 rcf, after which approximately three-quarters of the buffer solution was removed. Deoxygenated Milli-Q water was added to the centrifuge vial and the particles were resuspended in the water by sonication. This process was repeated a total of three times for each sample to prevent precipitation of buffer salt upon preparation of the TEM sample. Particles were mounted onto a TEM grid by placing a drop of the suspension on the grid. The TEM samples were prepared in the anaerobic glove bag and stored in an air-tight container until mounted onto the TEM sample holder. After all respikes were completed, particles were dried under N_2 and collected to characterize the solids by XRD.

Trifluralin was degraded by the Fe(II)/goethite system within the first three hours of reaction. Kinetic data was fit using a pseudo-first order model. Plots of $\ln(C/C_0)$ versus time were linear, which indicated that the degradation of trifluralin was well described by pseudo-first order kinetics. Figure 1 shows a plot of the kinetic data for each spike performed. Figure 2 shows a plot of the pseudo-first order rate constants calculated for the sequential respikes.

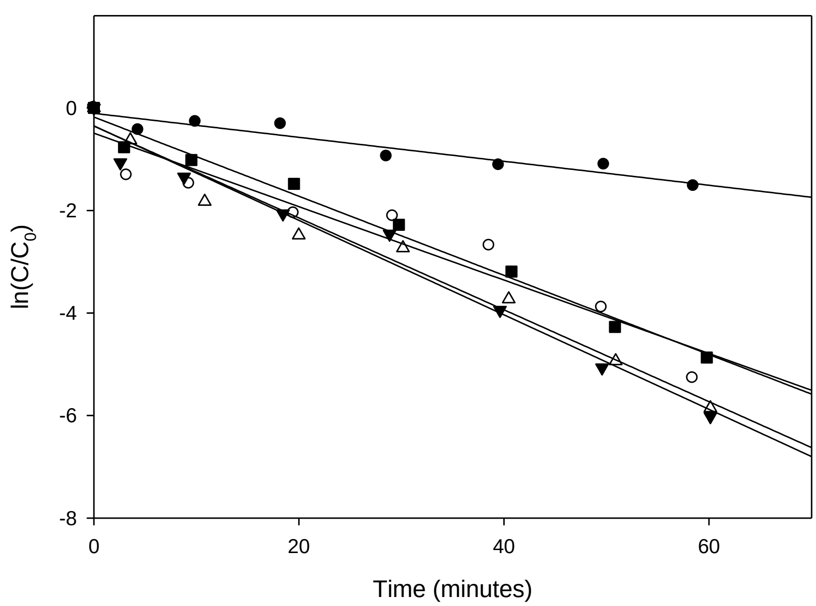

Figure 1. Degradation of trifluralin in sequential spike experiments with an Fe(II)/goethite suspension at pH 7.5. 1st spike (•); 2nd spike (o); 3rd spike (▼); 4th spike (Δ); 5th spike (■).

The pseudo-first order rate constant increased substantially after the first spike. Overall, the rates of reduction of trifluralin for injections #2-5 were faster than that of the original spike.

Rate constants for injections #2-5 were statistically indistinguishable from each other. Approximately 10% of the Fe(II) (initial concentration 1 mM) was used during each reaction cycle.

XRD data indicated the presence of goethite and magnetite after reaction with trifluralin after 5 reaction cycles, which was unexpected. Magnetite was observed in TEM images after the 4^{th} and 5^{th} spikes, suggesting that it formed throughout the respike experiments. Previous work with these particles did not see the formation of magnetite during the reduction of 4-chloronitrobenzene (4-Cl-NB), suggesting that magnetite was formed as a result of reaction with trifluralin.

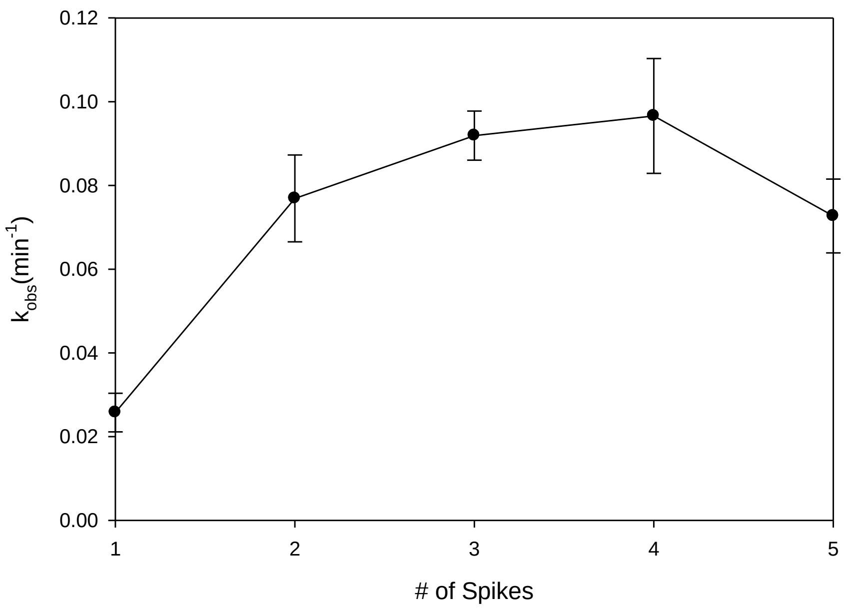

Figure 2. Reduction rate constants for trifluralin for five injections. Error bars are 95% confidence intervals.

The ratio of Fe(II) to goethite, however, was significantly different, in that the trifluralin experiments had a much higher ratio of Fe(II) to goethite mass compared to the 4-Cl-NB experiments. Aging experiments were performed using each system's Fe(II)/goethite loading to determine if this influenced the formation of magnetite. Contaminant blanks (i.e. batch reactors prepared with all components except for the trifluralin stock solutions) were prepared in order to test the possibility of magnetite formation due to exposure to ferrous iron. Blank reactors were placed on rotators for five days, which was the equivalent time to complete a trifluralin reaction series. Comparison of the XRD data from the two goethite systems indicates an absence of magnetite in both, further supporting the idea that magnetite was formed during reaction of the trifluralin with the Fe(II)/goethite system.

TEM analysis of the goethite particles after each trifluralin spike indicated aggregation during reaction with trifluralin had occurred. Large, sea urchin-like aggregates were observed after each trifluralin spike (Figure 3). Individual particles, as observed before reaction, were not observed after reaction. Quantification of single crystal growth could not be performed due to the aggregation of the particles. The diameters of the aggregates were measured for each of the spikes, and average aggregate diameters were calculated. The average diameter of the aggregates increased over the course of the injections from 2 μm (after the first spike) to 5 μm after the fifth spike. The density of the aggregates also appeared to increase over the course of the injections (Figure 3).

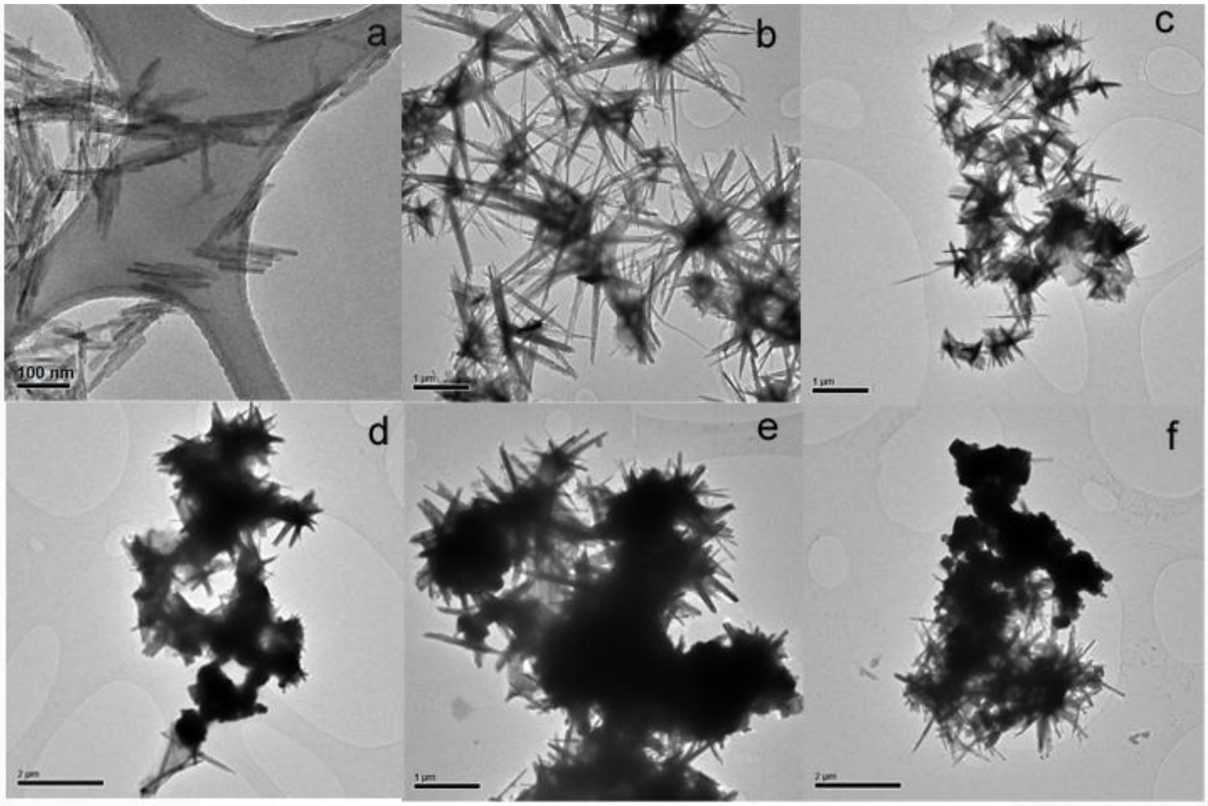

Figure 3. TEM images of goethite particles: a) before reaction and after each spike: b) 1^{st} c) 2^{nd} d) 3^{rd} e) 4^{th} f) 5^{th}.

The increase in reactivity over the time of the Fe(II)/goethite system could be attributed to the formation of magnetite. Iron(II) with magnetite has been shown reduce nitroaromatic compounds more quickly than Fe(II) and goethite systems. This could also account for the continuously higher reactivity of the Fe(II)/goethite systems over the course of the respikes. The increase in aggregate size could also be preserving the reactive surface of the particles, allowing for higher reaction rates after the first trifluralin spike The reduction of the trifluralin could be changing the surface of the particles along all directions, influencing the aggregation of the particles.

Reactions were also performed using trifluralin in an Fe(II)/goethite sand suspension. Trifluralin was degraded by this natural material, but at much slower rates than by the goethite nanoparticles. Rate constants for two reactors are shown in Figure 4. The pseudo-first order rate constants for each spike were statistically indistinguishable from one another. This implies that the reactivity of the sand is unchanged by multiple spikes of the trifluralin. Overall, the rate constants appear to decrease over the course of the respike experiments. The difference in the rate constants between the two reactors is probably due in part to the heterogeneity of natural sediments.

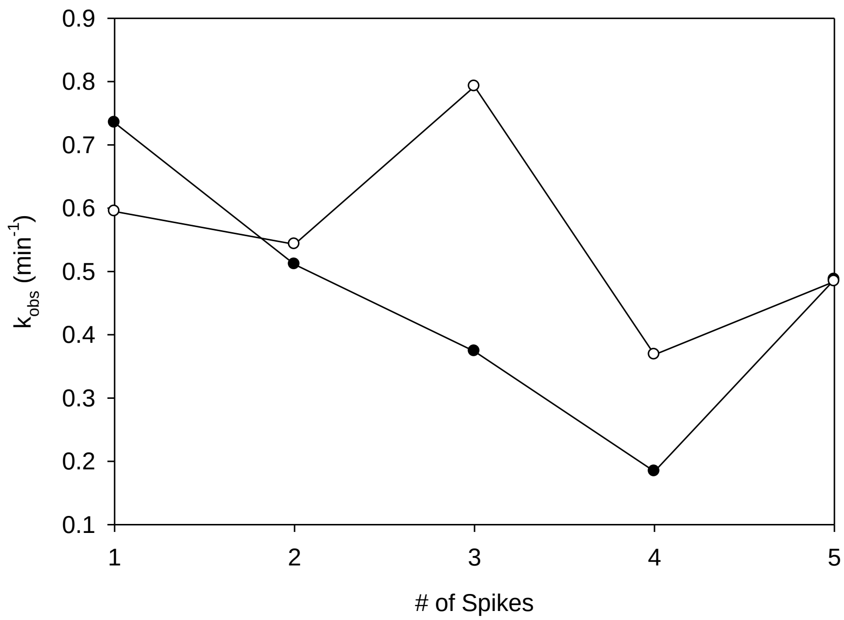

Figure 4. Reduction rate constants for trifluralin for five injections for reactions with Fe(II)/goethite sand suspension at pH 7.5. Data for two reactors is denoted by (●) and (○).

XRD of the sand before and after reaction did not show any significant changes over the course of the respikes. This is likely due to the small amount of iron present in the sand, as only 0.751 wt% was comprised of iron oxide, while 97 wt% of the sand was silica based on ICP-OES analysis of the sand. Magnetite was not detected in the sand after five reaction cycles with trifluralin. It is possible that magnetite either did not form or formed in quantities below the XRD detection limit. Comparison of the synthetic and natural goethite materials is difficult based on the data presented and would require additional work to draw more meaningful comparisons and conclusions.

Results to date suggest that mesotrione undergoes reductive degradation in the Fe(II)/goethite system. The reproducibility of the experiments is inconsistent. Experiments are ongoing to verify the results and determine accurate rate constants.

Publications

Project provided ancillary support for

Moore, K., B. Forsberg, D. R. Baer, W. A. Arnold, and R. L. Penn. 2011. Zero Valent Iron: Impact of Anions Present During Synthesis on Subsequent Nanoparticle Reactivity. *Journal of Environmental Engineering*, accepted.

Conference abstracts are listed under Presentations.

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Name: Kirsten Moore
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Degree: B.S. May 2011

Presentations

Penn, R.L., K. Moore, T. A. Do, and W. A. Arnold. Impact of Aggregation State on the Evolving Reactivity of Iron Oxide Nanoparticles. American Chemical Society 241st National Meeting, Anaheim, CA, March 31, 2010.

Arnold, W.A., R. L. Penn, K. Moore, A. Do, A. M. Stemig. Unexpected Changes in Aggregation and Mineralogy of Goethite During the Reduction of Nitroaromatics. Goldschmidt 2011, Prague, Czech Republich, August 14-19, 2011.

Related Funding

Evolution of reactive surface area, mineralogy, kinetics, and aggregation during iron oxide mediated contaminant transformation
National Science Foundation
PI: R. Lee Penn; co-PI: W. Arnold
$459,412
August 2010-August 2013

Fate and bioavailability of litter mercury in Minnesota streams and rivers

Basic Information

Title:	Fate and bioavailability of litter mercury in Minnesota streams and rivers
Project Number:	2009MN250B
Start Date:	3/1/2009
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	4
Research Category:	Biological Sciences
Focus Category:	Toxic Substances, Water Quality, Ecology
Descriptors:	None
Principal Investigators:	Jacques C. Finlay, Edward A Nater

Publications

1. Tsui, M.T.K., J. C. Finlay, S. J. Balogh, and E. A. Nater. (in prep) Changes of Leaf Litter Mercury Concentrations During In-situ Decomposition in Different Minnesota Streams.
2. Tsui, M.T.K., 2010. Mercury Bioaccumulation and Methylation in Stream Ecosystems. PhD thesis in Water Resources Science, University of Minnesota, 128 pages.

Fate and bioavailability of litter mercury in Minnesota streams and rivers

Principal Investigators
Jacques C. Finlay, Associate Professor, Department of Ecology Evolution and Behavior

Funding Source: USGS-WRRI 104B/CAIWQ Grants Program

Project Duration: 3/1/09-2/28/11
Reporting Period: 3/1/10-2/28/11

1) RESEARCH

1.1 Introduction

Atmospheric emission and transport is the dominant pathway leading to a global distribution of mercury (Hg) (Fitzgerald et al., 1998). One little studied pathway for entry of Hg to aquatic ecosystems is through trees and other terrestrial plants. Foliar uptake of atmospheric Hg occurs through stomatal exchange (Grigal, 2002; Ericksen et al., 2003). During autumn, senesced foliage falls onto forest floor and for those within riparian zone into stream channels.

Litter fall represents an important carbon input to support biological growth in stream and river ecosystems, especially for headwater streams (Finlay, 2001). However, litter fall also represents a large flux of inorganic Hg (Hg^{2+}) to stream ecosystems, and the bioavailability of this Hg^{2+} pool to stream biota is largely dependent on how much fraction of this Hg^{2+} pool can be converted to highly bioavailable methylmercury (MeHg) species. Previous field observations in an agricultural stream in south-central Minnesota demonstrated in situ Hg methylation of decomposing leaf litter in the stream channel (Balogh et al., 2002), which resulted in several fold increase in aqueous MeHg concentrations. More recently, it was demonstrated that streamwater characteristics such as particulate matter and sulfate levels may be important in determining litter Hg release and subsequent Hg methylation during litter decomposition in a laboratory incubation experiment at hypoxic conditions (Tsui et al., 2008).

In this study, we hypothesized that streams of varying streamwater properties may have different influences on the fate and transformation of the Hg^{2+} pool in decomposing leaf litter during in situ decomposition. In the current study, we carried out a field decomposition experiment of maple leaf litter collected from the same site (i.e. same physicochemical and Hg contents) and placed the maple litter in different streams in Minnesota draining contrasting land cover types in order to evaluate how the ambient properties in the stream channels influence on Hg concentrations in the decomposing maple litter, as well as other major elemental concentrations. Maple litter was selected because of its ubiquity in the upper Midwest region and its well characterized tissue composition (Hobbie, 2005).

1.2 Materials and Methods

1.2.1 Study sites. The ten streams in this study were located along a north-south geographic gradient in eastern Minnesota (Fig. 1). These streams are mainly located in three regions in Minnesota (agriculture in the south, mixed land uses in the Twin Cities Metro Area, and forest/wetland in the east). These streams drain different sizes and types of landscapes as summarized in Table 1. There is no known history on point sources of Hg (e.g. industrial discharge) in these study watersheds. We utilized the gradient in physiochemical conditions to evaluate effects Hg concentrations and speciation of leaf litter during in situ decomposition.

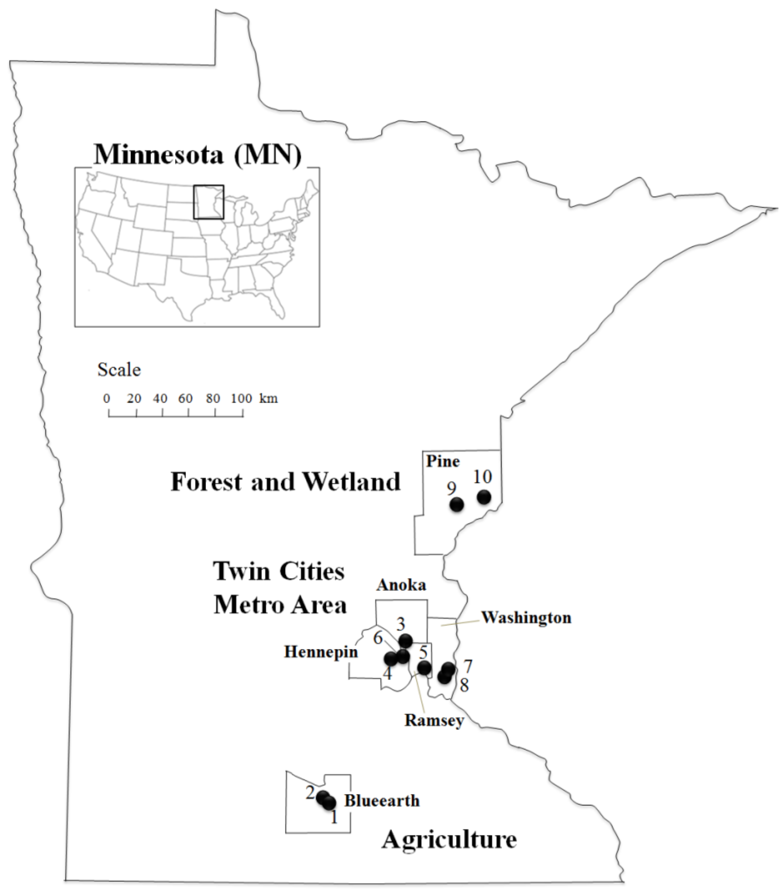

Fig. 1 Map showing locations of study streams in Minnesota (refer ID to Table 1).

1.2.2 Decomposition experiments. Newly fallen maple (*Acer sacrum*) litter was collected between late September and early October, 2009 at the Cedar Creek Ecosystem Science Reserve of the University of Minnesota (East Bethel, MN). Litter was hand-picked by personnel wearing non-powder cleanroom gloves, and placed into clean plastic bags. Upon return to the laboratory, litter was air-dried for 2-3 days inside a class 100 laminar-flow clean bench, and dried litter was stored in clean zip-lock bags prior to further use. Nitex bolting cloth with a mesh size of 1 mm (Wildlife Supply Company, Yulee, FL) was used to construct litterbags for this study. Litterbags of approximately 15 cm × 15 cm were sewn with double nylon threads by a sewing machine, cleaned to remove any residue Hg by being soaked in 10 % HCl overnight and rinsed thoroughly with nanopure water, and finally clean litterbags were air-dried in a clean bench. Air-dried litter was weighed (2.50 ± 0.10 g) and placed carefully into individual litterbag with gloved hands, and the bag opening was finally closed by sewing an additional nylon thread using a sewing machine in a clean bench. Individual litterbags were tagged with unique color cable ties and/or color label identifier (Fig. 2).

Fig. 2 Picture showing a litterbag with weighed maple litter, with a unique identifier.

During mid October 2009, individually weighed litterbags were secured to a nylon rope which was attached to a rebar secured into the streambed of the ten study streams. Litterbags were deployed in slowly flowing areas within the stream channels where litter accumulation naturally occurs. Twenty litterbags were deployed at each site and four litterbags (i.e. 4 replicates) were retrieved destructively at each time point (i.e. about 2 weeks, 5-weeks, 10-weeks and after snowmelt in the following year, 2010, or about 24-27 weeks). Upon retrieval from the field, litterbags were placed in new zip-lock bags, transported on ice to the laboratory, and frozen immediately. However, we were unable to retrieve several litterbags (*noted below*) due to either high flow or frozen surface for the following streams and time: 10-weeks for Big Cobb River, Maple River, Sand River and Lower Tamarack River; spring for Big Cobb River and Maple River).

At the same time, surface water samples were collected in this study and measured for water quality parameters in order to understand if these water characteristics are related to any observed changes of Hg concentrations associated with the decomposing leaf litter. Briefly, surface water was collected into two 500 mL vigorously acid-cleaned Telfon bottles using trace-metal clean techniques. Also, an additional 1 L HDPE bottle was used to collect surface water for analyzing total suspended solid (TSS) levels. All water samples were transported on ice to the laboratory for further processing within 24 h. In situ measurements were performed for water temperature and/or pH with an Orion portable pH meter (Model 250A) with daily calibration.

1.2.3 Water sample processing and analyses. Upon return to the laboratory, water samples in one of the Teflon bottles were directly sub-sampled (i.e., unfiltered fraction) or filtered through a 0.45-μm cellulose nitrate membrane housed in a disposable acid-leached filter unit (i.e., dissolved fraction). Samples were placed into acid-cleaned 125 mL Teflon bottles, and spiked with either 0.8-2 % BrCl (depending on actual organic matter content) for total-Hg analysis or 0.4 % of HCl for MeHg analysis (Parker and Bloom, 2005). For total-Hg, water samples were digested with BrCl overnight at 60 ^{o}C and pre-reduced by $NH_2OH{\cdot}HCl$ prior to the analysis, reduced by $SnCl_2$ in sparging flasks and Hg(0) was purged by Hg-free Ar gas and quantified by gold amalgamation technique with cold vapor atomic fluorescence detection (Liang and Bloom, 1993). For MeHg, acidified water samples were distilled to remove matrix interferences, ethylated and purged onto Tenax® traps (Brooks Rand) using Hg-free N_2 gas, and MeHg was quantified by cold vapor atomic fluorescence spectrometer after GC separation and pyrolysis (Bloom, 1989; Liang et al., 1994).

For another Teflon bottle, water was filtered through a muffled Whatman GF/F filter (pore size of ~ 0.7-μm) using glassware pre-rinsed with dilute HCl and nanopure water, filtered samples were acidified with HCl to < pH 2 for determining dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) by Shimadzu total organic carbon/total nitrogen analyzer (Series VModel cpn; Shimadzu Corporation, Kyoto, Japan), unpreserved for analyzing dissolved sulfate by Dionex DX120 Ion Chromatograph (Research Analytical Laboratory, University of Minnesota), or acidified with 1 % trace-metal grade HNO_3 (J. T. Baker) for quantifying dissolved cations and phosphorus (TDP) by Thermo Scientific iCAP 6500 dual view ICP-OES (Department of Geology and Geophysics, University of Minnesota). Water samples of known volume from the HDPE bottle were filtered onto pre-weighed Whatman GF/F filter paper which was then oven-dried and re-weighed again to determine TSS levels.

1.2.4 Litter sample processing and analyses. Frozen litterbags were individually freeze-dried (FreeZone 4.5, Labconco, Kansas City, MO). Since there were variable amount of external particles (e.g. fine clay, silt, sand, organic detritus, etc.) deposited onto the litter from stream flow, loosely associated particles were ; we assumed that fine particles that could not be removed were incorporated into the decomposing leaf litter biomass by microbial immobilization. We did not determine the mass loss of absolute amount of decomposing leaf litter in each litterbag since the associated particles were variable in litter over time and stream types, which could lead to underestimation of the actual loss of litter biomass. Afterward, we transferred the processed leaf litter samples into clean zip-lock bags for further chemical analyses (*see below*). Samples were not powdered because this may result in heterogeneous fractionation of the fine particles and leaf litter. Instead of this approach, we trimmed the leaf litter into finer pieces with gloved hands, and these small pieces were gently mixed within the sample bag and randomly selected for further chemical analyses (*see below*).

For total-Hg, leaf litter was weighed (0.05-0.20 g) into an acid-cleaned Teflon thick-walled digestion vial (Savillex, Minnetonka, MN). Weighed samples were added with 10 mL of concentrated HNO_3 and 10 mL of concentrated H_2SO_4 (both Certified ACS Plus, Fisher Scientific), and the slurry was swirled and left overnight with loose cap at room temperature. On the following day, the digestion vial was sealed tightly and placed in an oven at 60 ^oC overnight. After complete digestion, aliquot (1 mL) of acid digest was analyzed for total-Hg as described for water samples above. Reagent blanks (acid only; all < 0.04 ng g^{-1}) and standard reference materials (NIST 1515 Apple Leaves and NIST 1547 Peach Leaves; all between 90-93 % of certified values) were conducted with each sample batch.

Following 2ml aliquots of acid digest (duplicate per sample) were diluted with nanopure water (total volume: 10 mL), and placed into new 15 mL polypropylene centrifuge vials, and analyzed for major cations and phosphorus by Perkin-Elmer 3000 ICP-AES (Research Analytical Laboratory, University of Minnesota).

For MeHg, leaf litter was weighed (0.10-0.25 g) into an acid-cleaned 60 mL Teflon distillation vial (Savillex, Minnetonka, MN). Weighed samples were added with 30 mL nanopure water, 0.6 mL of 20 % KCl, 1.5 mL of 8 M H_2SO_4, and mixed thoroughly, and the mixture was distilled at 120-130 ^oC according to Horvat et al. (1993) and Morrison and Watras (1998). Distilled samples were buffered at pH 4.9, ethylated and purged onto Carbotrap® traps (Supleco) with Hg-free N_2, and analyzed for MeHg similar to the method for water samples. Blanks were always undetectable for MeHg while plant-like reference material certified for MeHg was not available during the time of this study.

1.3 Results and Discussion

1.3.1 Streamwater. Streamwater characteristics among 10 study streams varied widely, probably due to the contrasting land cover as well as geological influences on water chemistry, with the former exerting larger effect. As summarized in Table 1, during the experimental period, DOC and dissolved Fe levels were remarkably higher in streams draining high percentage of forest and wetland in the watersheds (# 9 and 10) while streams draining predominantly agricultural landcover (# 1 and 2) had relatively high levels of TDN, TSS and SO_4. Streams in Twin Cities Metro Area (# 3, 4, 5, 6, 7 and 8) with mixed land covers in their watersheds had variable levels of streamwater characteristics. For aqueous Hg, both total-Hg and MeHg levels were generally higher in streams with higher wetland covers (# 1 and 2), while aqueous MeHg levels were relatively low in streams located within Twin Cities Metro Area (except # 6, which drains north central Minnesota). Water temperature dramatically decreased after the beginning of the experiment (October, 2009) in all streams and reached near freezing (except # 5, 6, 7) at the end of December, 2009 (Fig. 3). However, in spring 2010 water temperature was elevated, even higher than the beginning of the experiment in October, 2009.

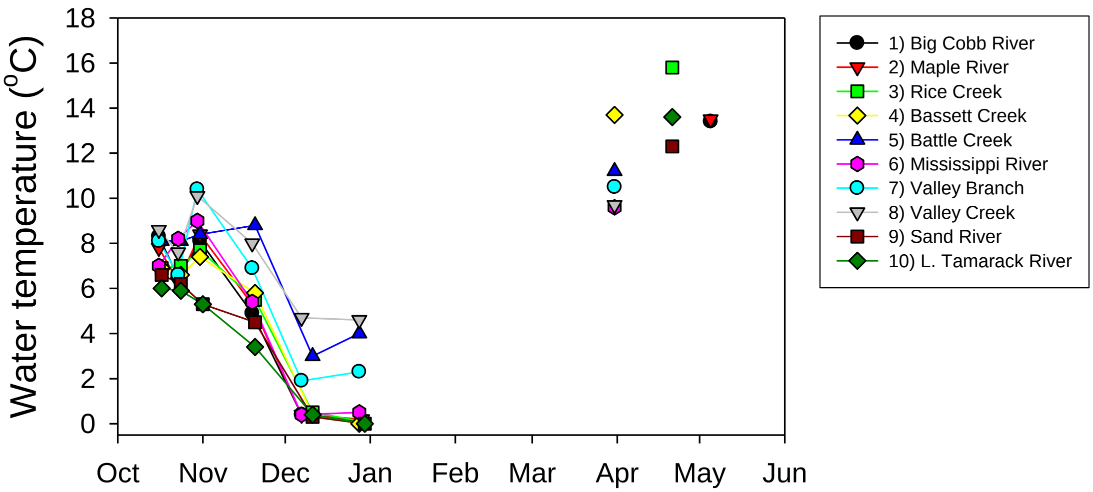

Fig. 3 Water temperature in study streams during the litter decomposition period (Fall 2009- spring 2010).

1.3.2 Litter. Visual inspection showed that, litter biomass decreased substantially over time, with litter collected at later times showing decreased integrity. There were very different particle types deposited onto the litter biomasses among stream types and over time.

After two weeks of *in situ* decomposition, all litter samples had elevated total-Hg concentrations (Fig. 4A), and it appeared that litter total-Hg concentrations continued to increase after five weeks. However, for the majority of streams we found no further increase in litter total-Hg concentrations after 10 weeks and in spring time. In contrast, elevation of litter total-Hg concentrations for both highly urbanized streams (# 4 and 5) occurred after the snowmelt period.

For MeHg, it appeared that for the majority of streams litter MeHg concentrations did not increase substantially until 10 weeks of decomposition, and for certain streams litter MeHg concentrations were more elevated than the others after winter snowmelt (Fig. 4B). Due to the larger increases of litter total-Hg compared to MeHg concentrations, the majority of streams had %MeHg even lower than the original litter after 10 weeks, but after the snowmelt period we found two streams which had elevated %MeHg (# 3 and 9) (Fig. 4C).

Table 1 Name of streams (ID same as in Fig. 1), watershed size and dominant land cover, median values of multiple measurements of major streamwater characteristic during the study period (*italic numbers* are the range of the data). *Note*: **WA** = watershed area; **D** = develop; **Ag** = agriculture; **F** = forest; **W** = wetland; **DOC** = dissolved organic carbon; **TDN** = total dissolved nitrogen; **TDP** = total dissolved phosphorus; **TSS** = total suspended solid; **Cond.** = conductivity; **TD-Fe** = total dissolved iron; SO_4^{2-} = dissolved sulfate; **UF** = unfiltered; **FIL** = filtered; **THg** = total-Hg; **MeHg** = methyl-Hg.

ID	Site name	WA	Major land covers D	Ag	F	W	DOC	TDN	TDP	TSS	Cond.	TD-Fe	SO_4^{2-}	UF THg	FIL THg	UF MeHg	FIL MeHg
		km^2	%	%	%	%	mg L^{-1}	mg L^{-1}	µg L^{-1}	mg L^{-1}	µS cm^{-1}	µg L^{-1}	mg L^{-1}	ng L^{-1}	ng L^{-1}	ng L^{-1}	ng L^{-1}
1	Big Cobb River	800	6	86	1	4	4.3 *3.7-6.0*	6.3 *0.6-10.2*	19.4 *9.7-135*	10.0 *2.4-40*	624 *571-678*	3.5 *0.5-26*	16.7 *14-23*	0.98 *0.9-3.3*	0.66 *0.6-0.9*	0.08 *<0.03-0.25*	0.05 *<0.03-0.07*
2	Maple River	905	6	86	1	3	4.2 *3.0-4.3*	6.4 *3.3-9.2*	52.6 *9.0-133*	9.3 *2.7-202*	745 *603-858*	4.3 *1.4-17*	29.5 *19-38*	1.0 *0.9-7.3*	0.60 *0.4-0.7*	0.09 *0.06-0.23*	0.04 *<0.03-0.08*
3	Rice Creek	249	46	17	13	10	9.2 *7.7-11.5*	0.91 *0.7-1.1*	12.3 *9.5-14*	4.7 *1.6-9.4*	563 *509-895*	53.3 *17-116*	4.5 *3.2-6.8*	0.73 *0.4-1.3*	0.44 *0.3-0.7*	0.04 *<0.03-0.08*	<0.03 *<0.03-0.08*
4	Bassett Creek	113	82	1	10	2	4.2 *3.7-8.1*	0.69 *0.5-0.8*	24 *12-56*	5.5 *2.2-22*	973 *658-1,403*	36.1 *2.3-173*	11.0 *8.6-16*	1.4 *0.6-2.4*	0.46 *0.2-0.7*	0.06 *0.05-0.09*	<0.03 *all <0.03*
5	Battle Creek [a]	4.9	96	0	3	0	0.6 *<0.1-34.5*	0.85 *0.4-1.1*	7.8 *3.2-21*	3.2 *1.3-28*	986 *827-1,267*	1.9 *0-21*	18.6 *18-20*	0.71 *0.4-4.0*	0.20 *0.1-0.4*	<0.03 *<0.03-0.09*	<0.03 *all <0.03*
6	Mississippi River [b]	51,500	3	44	33	12	6.7 *6.3-7.4*	1.9 *1.1-3.2*	34.2 *16-62*	9.3 *1.6-17*	453 *373-555*	33.8 *18-108*	6.7 *6.3-13*	1.5 *0.7-3.8*	0.57 *0.6-2.1*	0.08 *0.05-0.15*	0.04 *<0.03-0.08*
7	Valley Branch	128	20	48	20	2	1.2 *<0.1-1.8*	3.5 *3.0-4.2*	11.7 *9.2-14*	3.5 *2.6-5.4*	486 *450-506*	7.7 *0-25*	4.4 *4.2-4.8*	0.52 *0.4-0.9*	0.29 *0.2-0.4*	<0.03 *<0.03-0.04*	<0.03 *all <0.03*
8	Valley Creek	20	5	64	25	0	< 0.1 *<0.1-0.38*	6.5 *6.4-6.8*	12.2 *5.6-15*	1.5 *0.9-8.9*	547 *538-550*	7.8 *1.4-14*	5.7 *4.1-6.2*	0.32 *0.3-0.7*	0.18 *0.1-0.2*	<0.03 *all <0.03*	<0.03 *all <0.03*
9	Sand River	198	2	12	60	19	11.6 *4.2-17.7*	0.59 *0.5-0.7*	15.4 *14-19*	2.2 *1.4-7.5*	107 *68-163*	1,363 *804-1,626*	0.96 *0.8-1.4*	2.6 *1.6-5.5*	2.1 *1.4-4.2*	0.14 *0.04-0.18*	0.13 *<0.03-0.20*
10	Lower Tamarack River	327	1	1	64	29	19.9 *15.7-22.6*	0.71 *0.7-0.8*	19.6 *16-30*	2.1 *0.7-5.4*	91 *56-148*	1,053 *890-2,353*	0.65 *0.5-1.3*	4.6 *3.0-6.3*	3.7 *2.6-5.6*	0.23 *0.17-0.37*	0.24 *0.17-0.32*

[a] a sub-catchment of Battle Creek

[b] Outdoor Stream Laboratory at St. Anthony Falls Laboratory, University of Minnesota

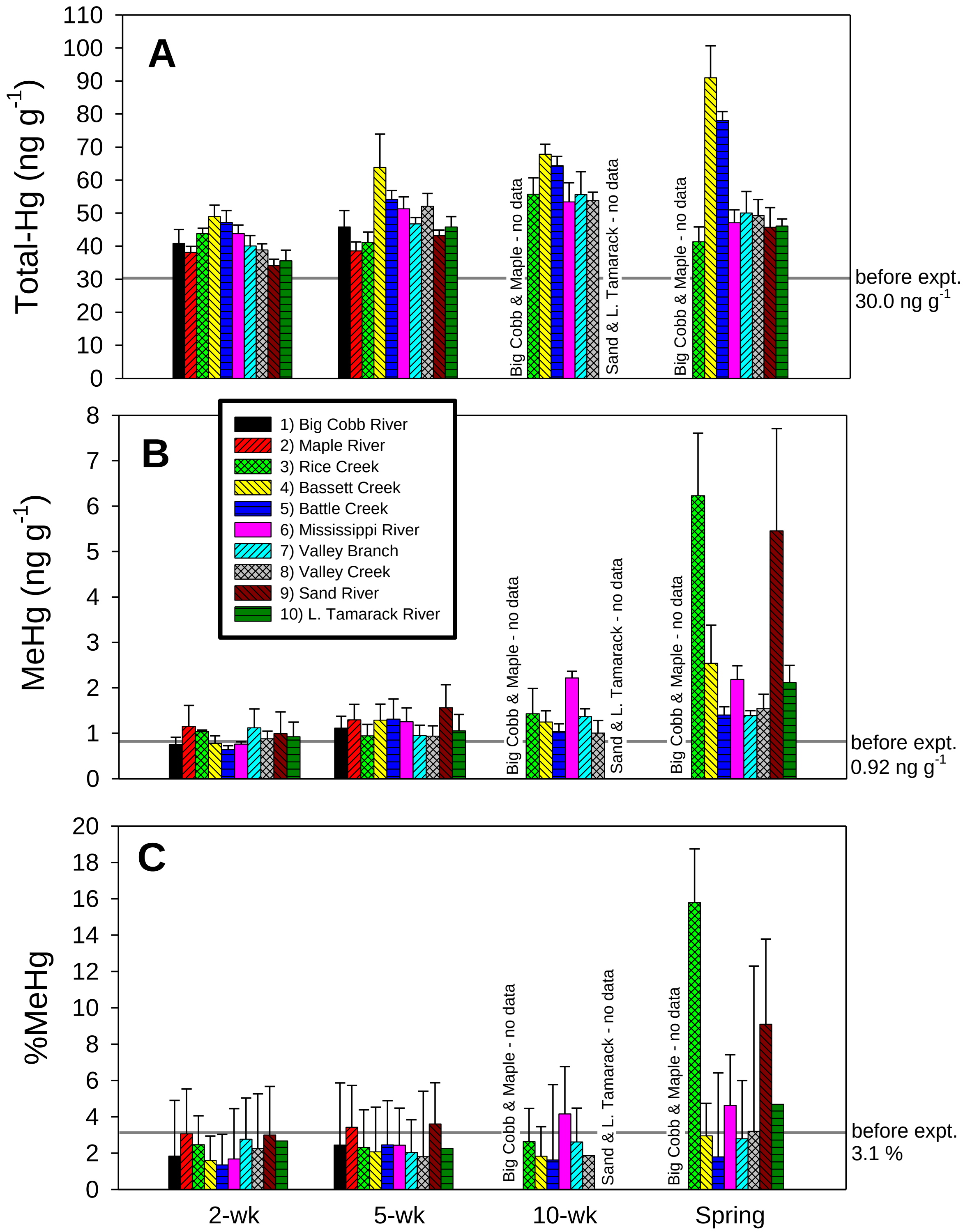

Fig. 4 Temporal changes of Hg concentrations and speciation in leaf litter during in situ decomposition: (A) total-Hg, (B) MeHg, and (C) %MeHg (or % total-Hg as MeHg). Error bars are standard deviation of four replicates.

However, we did not find any good evidence to support that these inorganic particles contributed to changes in litter MeHg concentrations (*analysis not shown*). Rather inorganic particles may have very low MeHg levels (e.g. lower than original litter MeHg levels) and may therefore have diluted litter MeHg concentrations through incorporation into the litter tissues (as evidenced by the increase in litter Fe levels). However, since litter MeHg concentrations for a few sites increased remarkably after the snowmelt period, we thus focused on whether the aqueous MeHg levels may mediate these changes during the winter period. As shown in Fig. 6A-D, we found that for a few sites dissolved MeHg levels in streams during winter period (average of samples before and after winter freezing period, excluding two agricultural streams due to non-sampling) may explain the increase in the litter MeHg concentrations (Fig. 6B) but the trend was not strong. It is possible that other site-specific factors (e.g. specific microbial communities for Hg methylation) may contribute to these inter-site differences in elevating litter MeHg concentrations, including in situ Hg methylation. In addition, cold temperatures and high streamwater oxygen levels during the period following leaf fall may serve to suppress methylation within leaf packs. These hypotheses could be tested in future studies.

1.4 Summary

Overall, this is the first study to examine how the *in situ* decomposition influences Hg concentrations in decomposing litter in streams. Hg dynamics during decompositions processes are an important determinant of how atmospheric Hg contributes to bioavailable Hg (i.e. MeHg) to stream food webs during litter fall and subsequent processing in stream channels. Our results suggest that inorganic Hg from the particulate phase in streams are important in changing the litter Hg levels while site-specific factors including dissolved MeHg levels and other chemical parameters may affect litter MeHg concentrations. Future work could address the role of the deposition environment and hydrology in determining Hg dynamics during decomposition in streams.

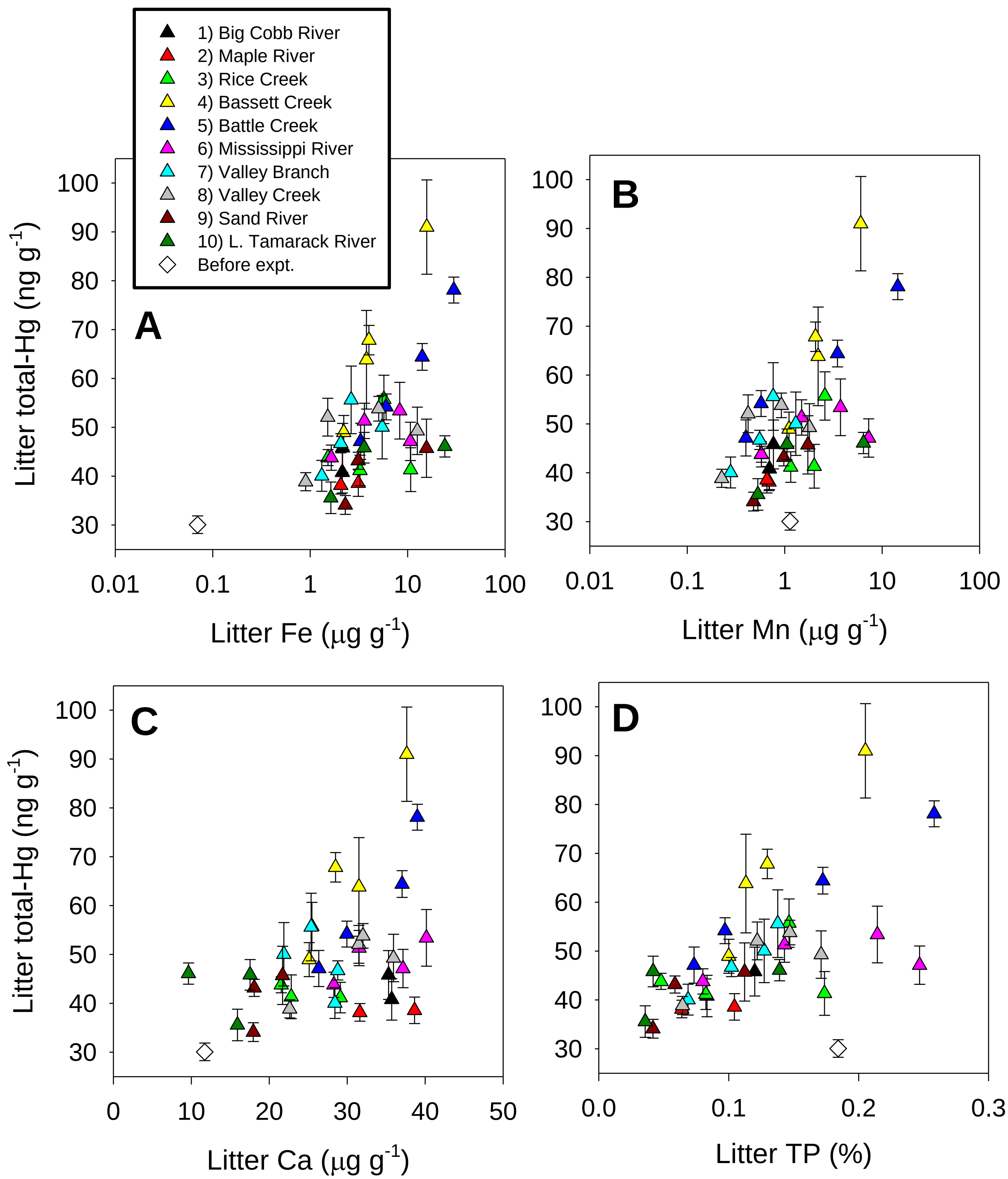

Fig. 5 Relationship between litter total-Hg and (A) litter Fe, (B) litter Mn, (C) litter Ca, and (D) litter total phosphorus (TP) concentrations. Open symbols are data for original maple litter. Error bars are standard deviation of four replicates for total-Hg measurements, while an average of duplicate measurements was used for other elements.

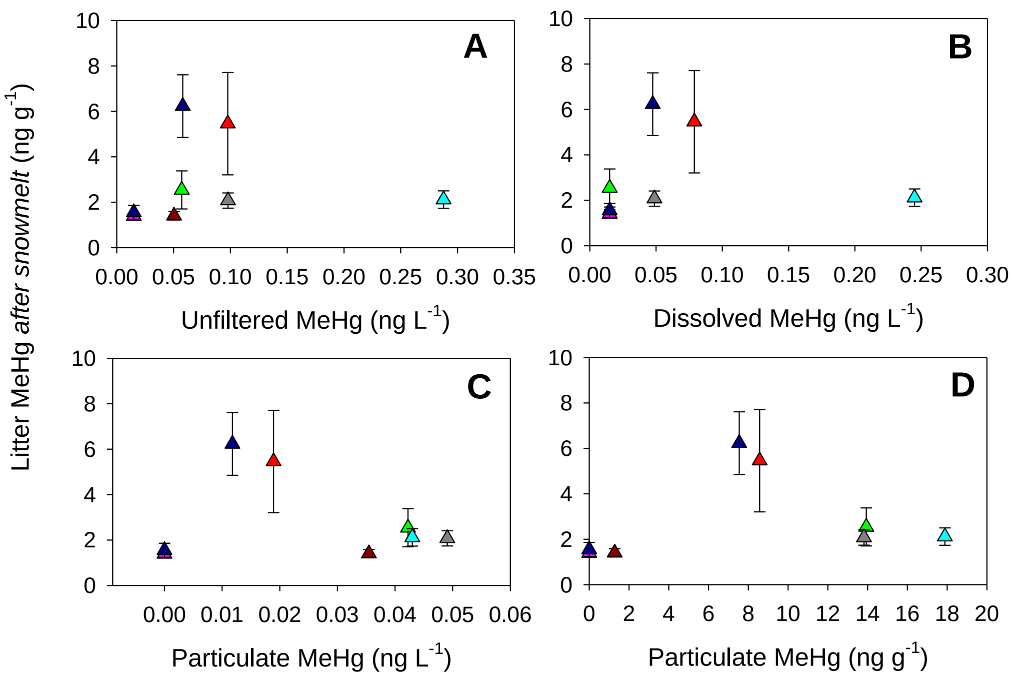

Fig. 6 Relationship between litter MeHg concentrations in spring 2010 and different pools of aqueous MeHg during winter period (i.e., average of last sampling in December 2009 and spring sampling): (A) unfiltered MeHg, (B) dissolved MeHg, (C) particulate MeHg in ng L^{-1}, and (D) particulate MeHg in ng g^{-1}. Error bars are standard deviation of four replicates for MeHg measurements.

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2) PUBLICATIONS

Tsui, M.T.K., J. C. Finlay, S. J. Balogh, and E. A. Nater. (in prep) Changes of Leaf Litter Mercury Concentrations During In-situ Decomposition in Different Minnesota Streams.

Tsui, M.T.K., 2010. Mercury Bioaccumulation and Methylation in Stream Ecosystems. PhD thesis in Water Resources Science, University of Minnesota, 128 pages.

3) STUDENT SUPPORT

Martin Tsui – PhD Candidate Research Assistant (WRS Program)
Yuntian Gu – Undergraduate Research Assistant I (CFANS major)
Stefanie Wolf – Undergraduate Research Project (UROP) (EEB major)

4) PRESENTATIONS

Tsui, M.T.K., J. C. Finlay, S. J. Balogh, and E. A. Nater. 2011. Changes of Leaf Litter Mercury Concentrations During In-situ Decomposition in Different Minnesota Streams. 10th International Conference on Mercury as a Global Pollutant. July 24-29, Halifax, Nova Scotia, Canada. (*abstract accepted*)

Tsui, M.T.K., J. C. Finlay. 2010. What controls methylmercury concentrations in stream biota? American Society of Limnology and Oceanography / North American Benthological Society Joint Summer Meeting. June 6-11, Santa Fe, New Mexico, USA.

Tsui, M.T.K., J. C. Finlay. 2009. Influences of Land Cover on Methylmercury Concentrations in Water and Invertebrates in Minnesota Stream Ecosystems. Minnesota Water Resources Conference. October 26-27, St. Paul, Minnesota, USA.

5) AWARDS

Tsui MTK

Universities Council on Water Resources; Honorable Mention, UCOWR's 2011 Ph.D. Dissertation Award

Department of Geological Sciences, University of Michigan; Turner Postdoctoral Research Fellowship 2011/2012

Finlay, JC

McKnight Presidential Fellowship, UMN 2009-2012

6) RELATED FUNDING

None

Urban Stormwater Inputs of Perfluorochemicals

Basic Information

Title:	Urban Stormwater Inputs of Perfluorochemicals
Project Number:	2009MN253B
Start Date:	3/1/2009
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	5
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Sediments, Solute Transport
Descriptors:	None
Principal Investigators:	Matt Francis Simcik

Publication

1. Xiao, F. J. Gulliver, and M. Simcik (presented by Feng Xiao). Do Perfluorinated Compounds Act Like a Solid in Competitive Adsorption onto a Solid/Water Interface? Poster presentation at the Gordon Research Conference on Environmental Sciences: Water in Plymouth New Hampshire June 2010.

Urban Stormwater Inputs of Perfluorochemicals

Principal Investigators
Matt F. Simcik, Associate Professor, Department of Environmental Health Sciences

Funding Source: USGS-WRRI 104B/CAIWQ Grants Program

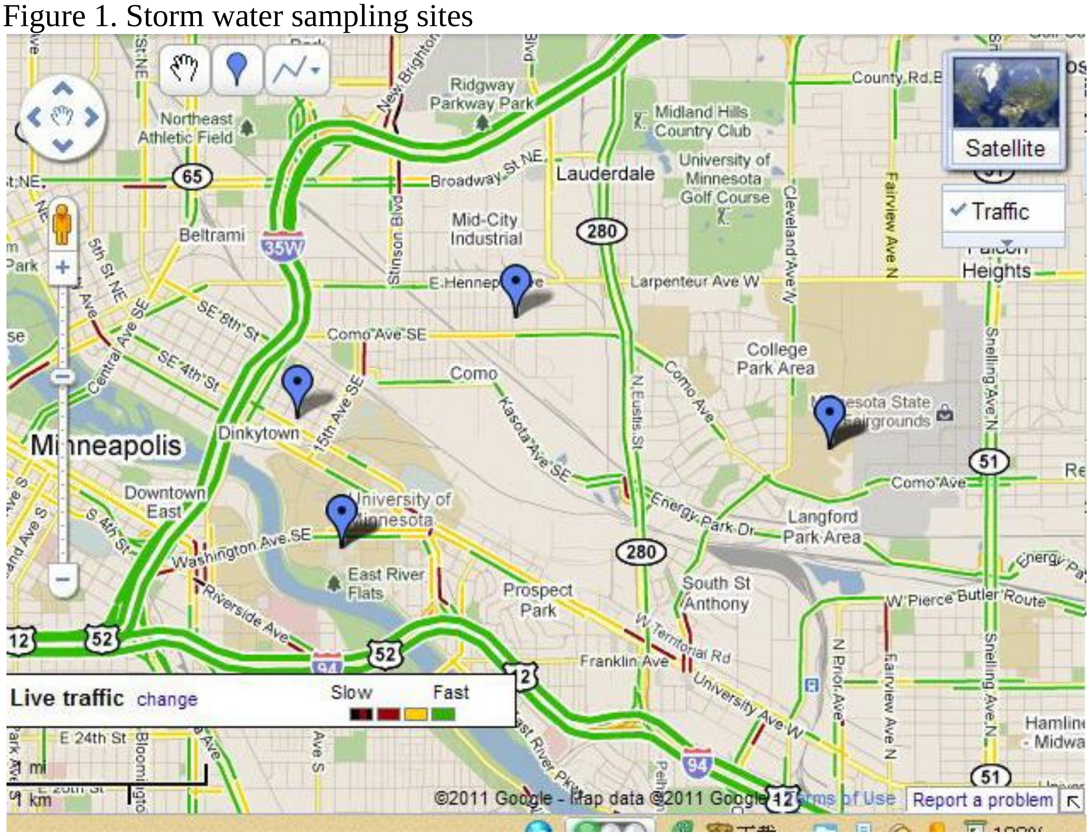
Project Duration: 3/1/09-2/28/11
Reporting Period: 3/1/10-2/28/11

Title: Urban Stormwater Inputs of Perfluorochemicals

1) _Research_: A synopsis of your ongoing research project and of any research project completed during this reporting period. This includes projects funded under the base grant and the National Competitive Grants program. These reports are for a technical audience, and are posted and regularly accessed on the main USGS website. We do not do any editing of these, so please take care in their preparation. Somewhere between 5-10 pages including tables and figures is typical.

Six stormwater events were sampled in residential and University areas of Minneapolis and St. Paul, MN. Samples consisted of 4L grab samples taken by lowering 4L HDPE bottles into the storm water flow from street level into drainage ditches. A map of the sites is given in Figure 1.

Figure 1. Storm water sampling sites



Water samples were filtered to separate the dissolved phase from the particulate phase perfluorochemicals (PFCs). Filters were 47mm polypropylene (Millipore) filters with 2um pore size. Several filters were required per water sample as the particles in the samples clogged the filters and head pressure increased (or flow decreased). The filtrate was then extracted using solid phase extraction cartridges packed in the laboratory with cleaned XAD-7 polymeric resin. The resin and filters were extracted separately with methanol (Optima grade, Fisher Scientific). Internal standards consisting of 13C labeled PFOS and PFOA were added to each extract and a suite of perfluorochemicals (Table 1) quantified by liquid chromatography/mass spectrometry (LC/MS) utilizing electrospray negative ionization (HP 1090 LC and Agilent 1100 MS).

PFC identification was performed by comparing retention times and m/z corresponding to native standards. The LC/MS was operated in the selective ion monitoring mode corresponding to the m/z for each analyte and standard.

Table 1. List of Analytes

Analyte	Abbreviation	CAS #
perfluorobutanoic acid	PFBA	375-22-4
perfluorobutane sulfonate	PFBS	375-73-5
perfluoropentanoic acid	PFPeA	2706-90-3
perfluorohexanoic acid	PFHxA	307-24-4
perfluorohexane sulfonate	PFHxS	355-46-4
perfluoroheptanoic acid	PFHpA	375-85-9
perfluorooctanoic acid	PFOA	335-67-1
perfluorooctane sulfonate	PFOS	1763-23-1
perfluorooctane sulfonamide	PFOSA	754-91-6
perfluorononanoic acid	PFNA	375-95-1
perfluorodecanoic acid	PFDA	335-76-2
perfluoroundecanoic acid	PFUnA	2058-94-8
perfluorododecanoic acid	PFDoA	307-55-1

Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid were the most frequently detected and highest concentration PFC contaminants measured in the six storm water events. Other PFCs were detected in less frequency (Figure 2).

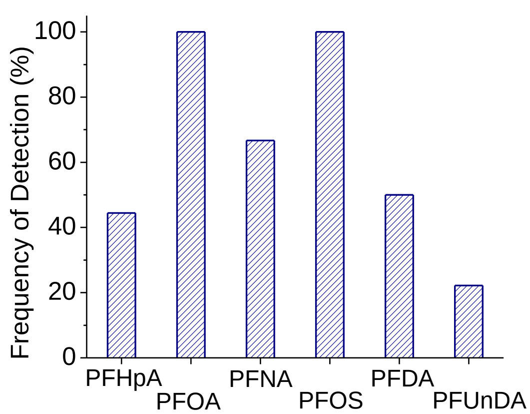


Figure 2. Frequency of detection: PFOS=PFOA>PFNA>PFHpA=PFDA>PFUnDA (based on the results
of Chi-square test).

Concentrations of PFOS and PFOA are presented in Figure 3. For the six storm events in 2010-2011 the concentration of PFOS and PFOA were quite similar and statistically greater than the concentrations of perfluoroheptanoic acid (PFHpA), perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA), which are statistically greater than the perlfuorododecanoic acid (PFDoA) concentration.

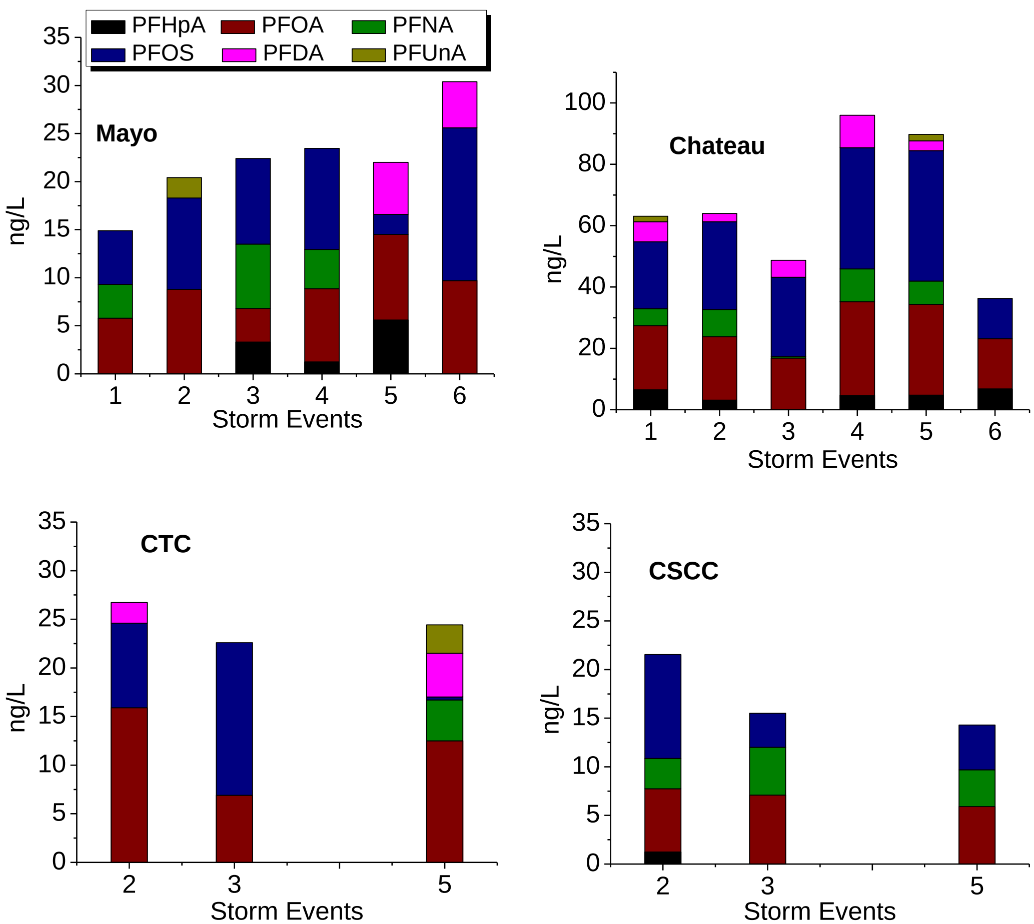


Fig. 3. PFAA concentrations in street runoff in different locations during six storm events. (Event 1: August 20 2010; Event 2: Sep 01 2010; Event 3: Sep 15 2010; Event 4: Sep 23 2010; Event 5: Oct 26 2010; Event 6: May 12 2011)

Only PFOS was detected in any of the particle phase samples. Three samples resulted in measurable PFOS ranging from 0.12 to 0.59 ng/mg of total suspended solids (TSS; Table 3).

Table 3. PFOS and PFOA on the total suspended solids (TSS) in stormwater runoff (2009, 9, 25)

PFAAs on particles in stormwater runoff, ng/gTSS						
	PFHpA	PFOA	PFNA	PFOS	PFDA	PFUnDA
36th and Brunswick [a]	ND	ND	ND	280.4	ND	ND
36th and Kenwood [a]	ND	ND	ND	120.5	ND	ND
351/2 [a]	ND	ND	ND	590	ND	ND
Chateau [b]	ND	ND	ND	19.8	ND	ND
CTC [b]	ND	ND	ND	ND	ND	ND
CSCC [b]	ND	ND	ND	ND	ND	ND
Mayo [b]	ND	ND	ND	ND	ND	ND
Chateau [c]	ND	ND	ND	45.9	ND	ND
CTC [c]	ND	ND	ND	ND	ND	ND
CSCC [c]	ND	ND	ND	ND	ND	ND
Mayo [c]	ND	ND	ND	ND	ND	ND
Chateau [d]	ND	ND	ND	ND	ND	ND
Mayo [d]	ND	ND	ND	ND	ND	ND

[a]: Sep 25 2009; [b]: Sep 01 2010; [c]: Sep 15 2010; [d]: May 12 2011

2) _Publications_:
Xiao, F., Z. Xiangru, M. F. Simcik, and J. S. Gulliver. Effects of Monovalent Cations on the Competitive Adsorption of Perfluoroalkyl Acids on Kaolinite: Hydrophobic and Electrostatic Interactions. *Water Research* **in review**.

Xiao, F., M. F. Simcik, and J. S. Gulliver. Perfluorochemicals in Stormwater: Occurrence and Partitioning. **in preparation.**

3) _Student Support_: This project has supported one Ph.D. student, Feng Xiao, in Civil Engineering at the University of Minnesota.

4) _Presentations:
Xiao, F. J. Gulliver, and M. Simcik (presented by Feng Xiao). Do Perfluorinated Compounds Act Like a Solid in Competitive Adsorption onto a Solid/Water Interface? Poster presentation at the Gordon Research Conference on Environmental Sciences: Water in Plymouth New Hampshire June 2010.

5) _Awards_: Civil Engineering travel award to Feng Xiao.

6) _Related Funding_: Proposal under review to MPCA/EPA 319 program.

The role of sulfate reduction in sediment of the St. Louis River estuary

Basic Information

Title:	The role of sulfate reduction in sediment of the St. Louis River estuary
Project Number:	2010MN269B
Start Date:	7/1/2010
End Date:	6/31/2011
Funding Source:	104B
Congressional District:	MN 8th
Research Category:	Water Quality
Focus Category:	Sediments, Toxic Substances, Geochemical Processes
Descriptors:	None
Principal Investigators:	Nathan Johnson

Publications

There are no publications.

The Role of Sulfate Reduction in the St. Louis River Estuary: Phase I

Principal Investigators

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Brian Beck, University of Minnesota Duluth**,** Department of Civil Engineering and Water Resources Science Graduate Program

Funding Source: USGS-WRRI 104B/CAIWQ Grants Program

Project Duration: 3/1/10-2/28/11
Reporting Period: 3/1/10-2/28/11

OBJECTIVES

Ongoing studies have been describing sulfate and methylmercury (MeHg) concentrations in the St. Louis River watershed in Northeastern Minnesota (Berndt and Bavin. 2009). The study described herein is an extension of the Berndt report, with relation to the role of sulfate in the St. Louis River Harbor sediment. The objective of Phase I (first year) of the Role of Sulfate Reduction in Sediment of the St. Louis River Estuary project was twofold. The first objective of this year's study was to characterize the bulk biogeochemical processes in the St. Louis Harbor. In the context of mercury methylation, we have sought to identify characteristic differences in the location and extent of biological sulfate reduction amongst the different aquatic habitat zones outlined by the St. Louis River Alliance (SLRA. 2002). The secondary objective of the first year was to refine analytical techniques for use in Phase II of the project. The objectives and methods planned for Phase II (second year) are briefly outlined at the end of this report.

METHODS

Field Sampling and Site Selection

Sediment sampling was conducted during the first week of October 2010 in the St. Louis River Estuary. The sampling involved collecting ~12-18" intact sediment cores from several of the major habitat zones (SLRA. 2002) in the St. Louis River Estuary (Figure 1). Sites were selected in four habitat zones both because of known differences

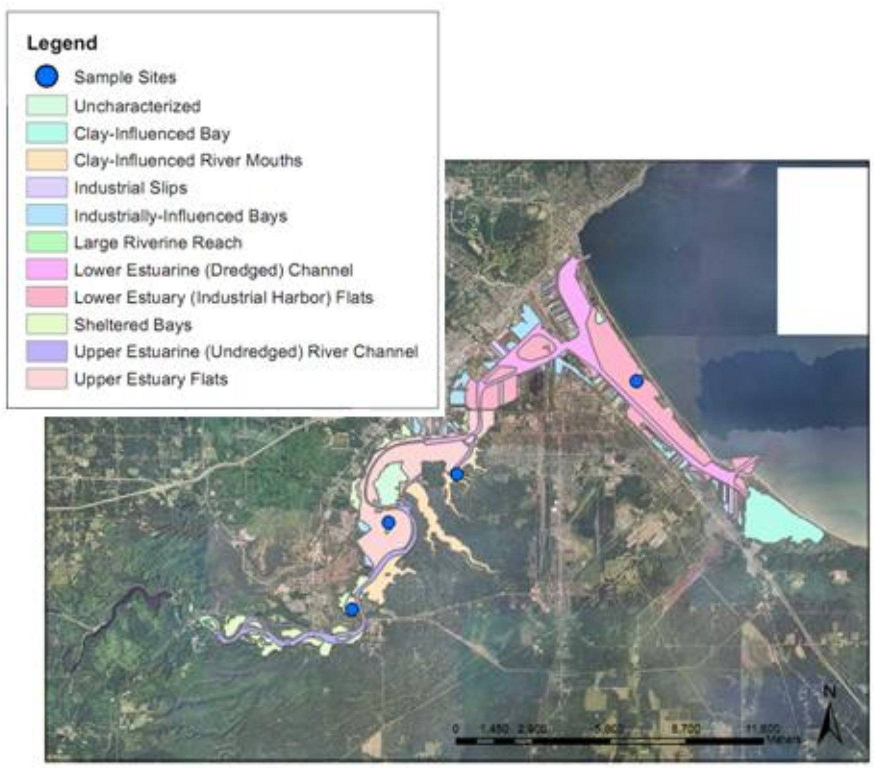

Figure 1. Sites (blue symbols) within selected Habitat Zones chosen to represent large portions of the St. Louis Estuary Harbor.

in bulk geochemical characteristics and because they were major contributors to overall estuary area. Sheltered Bays (SB), Lower Estuary Flats (LEF), Upper Estuary Flats (LEF), and Clay Influenced Mouths (CIM) (Figure 1 and Figure 2) make up over half of the overall Estuary surface area and cores were collected from each of these zones. Since major geochemical differences exist amongst the habitat zones, it is anticipated that individual cores will represent the bulk geochemistry of the habitat zone. Visually, the Sheltered Bay and Upper Estuary Flats were the darkest cores, with a silty texture, although the Upper Estuary Flat was sandier and slightly lighter in color. Both the Upper Estuary Flats and Sheltered Bay had clear dark laminations at multiple depths. The Clay Influenced Mouth was lighter in color (grey in color), with a very clayey texture. The Lower Estuary Flat core was primarily sand, had the lightest color, and few laminations.

In addition to the aquatic habitat zones context, a downstream sulfate gradient conceptual model was incorporated into sediment sampling. In the lower St. Louis River system, there is generally a high to low downstream gradient in dissolved constituents carried by the river to Lake Superior (Oster et al. 2010). Similar longitudinal gradients have been observed in marine estuary systems, only reversed with regard to sulfate transported from sea water (Hammershmidt et al. 2004). Another gradient of importance in driving sulfate reduction and concomitant mercury methylation is an organic carbon gradient along the harbor from high concentrations upstream to low concentrations downstream. First year sampling sites were designed to capture the expected downstream gradients of sulfate and organic carbon concentrations in the St. Louis River estuary.

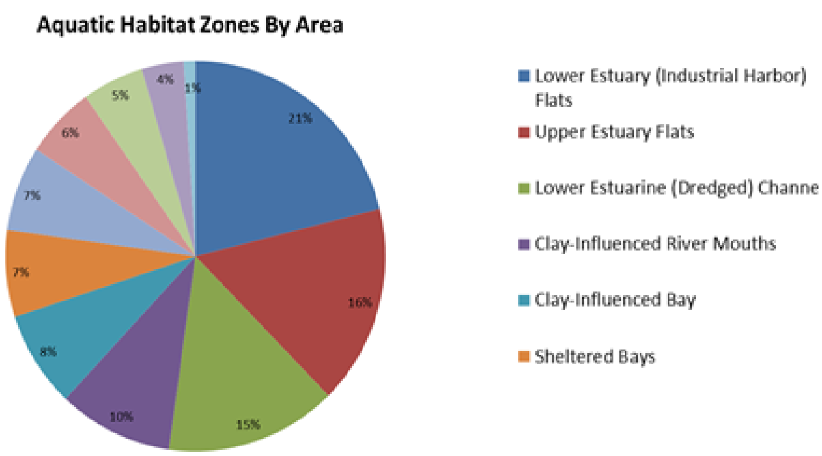

Figure 2. Each habitat zone by percent area within the St. Louis River Estuary. The four zones select for this study accumulate to 54% of the total area in the estuary.

Sediment cores were collected using a 2.5 cm piston corer, supplied by the National Lacustrine Core Facility (LacCore), which was used to ensure an intact sediment water interface (SWI). In addition to taking sediment samples at each site, surface water grab samples were collected using acid cleaned Pyrex media bottles. Sediment cores were taken back to the UMD-Civil Engineering laboratory and immediately refrigerated until further processing. Although cores were taken from each of the four sites listed above, only three cores were used for geochemical investigations during the Phase I study.

<u>Dissolved Porewater Analysis</u>

Voltammetric analysis of sediment powerwater was used to obtain relative abundance of dissolved ΣS^{2-} ($H_2S_{(aq)}$ and $HS^-_{(aq)}$), Fe^{2+}, Mn^{2+}. Electrodes were fabricated in the laboratory using a standard voltammetry electrode method (Brendel and Luther 1995). Electrodes were calibrated using a single point method to identify peak locations of desired analytes (Mn^{2+}, Fe^{2+}, ΣS^{2-}) during voltammetric scans. Electrodes were calibrated in a buffered matrix consisting of St. Louis River water filtered through a 0.45 µm filter with a measured pH of 6.7 (in standard units). Calibration solutions were made using ACS grade $MnCl_2{\bullet}4H_2O$, $FeCl_2{\bullet}4H_2O$, $Na_2S{\bullet}9H_2O$ for a one point calibration. Using a one point calibration limited reporting to relative magnitudes of each dissolved species instead of concentrations. Electrodes were found not to be working properly after the analysis of the Sheltered Bay (SB) core when reference standards were run after the core had been scanned. Time constraints did not allow regeneration of the electrodes and rescanning of cores.

Solid Phase Sediment Analysis

Cores were sectioned into lengths from 1 cm to 5 cm using a core extruder and spatula (covered in parafilm), delivered to acid cleaned jars, and immediately placed in a N_2 atmosphere to be homogenized. Sediment slices were homogenized and split for separate analyses. Samples for mercury and methyl mercury analysis were immediately frozen at -20°C until extraction and analysis. Acid Volitile Sulfides (AVS) were measured using the Brouwer diffusion method (Brouwer and Murphy. 1994). A quantitative mass of sediment was added to a 20 mL scintillation vial under an N_2 atmosphere. After sediment was added, a 2 mL centrifuge tube filled with a sulfide anti-oxidant buffer (SAOB) was placed in scintillation vial. Each scintillation vial was then hermetically sealed with a Minninert lid and removed from the N_2 chamber. 2N HCl was added via syringe through the Minninert valve to the sediment and placed on a shaker table for 60 minutes. After this extraction time, the SAOB containing extracted sulfide was poured into a separate scintillation vial where sulfide was quantified using a sulfide ion selective electrode (ISE). Bulk sediment total organic carbon, carbon, and sulfur (TOC, TC, and TS respectively) were analyzed using Total Sulfur and Carbon Coulometric Analyzer (UIC Corporation). Remaining sediment was centrifuged at 10,000 rcf for 30 min and filtered with a 0.45 µm filter. DOC was measured using a Total Organic Carbon Analyzer (Shimadzu) after being acidified to a pH of 1.5 using HNO_3. Filtered porewater samples were sent to a commercial lab to be analyzed for sulfate (SO_4^{2-}) with Ion Chromatography (IC). Methylmercury was extracted from a quantitative amount of sediment using 1 M HNO_3 and 7 M NaOH, according to methods outlined by Hammerschmidt (2001), followed by analysis via ethylation, pyrolysis, and cold vapor atomic fluorescence.

RESULTS

Dissolved Porewater

Figure 3c depicts depth profiles of porewater sulfate concentrations in the Lower Estuary Flats (LEF), Clay Influenced Mouth(CIM), and Sheltered Bay (SB) sediment. Figure 3a and 3b depict relative

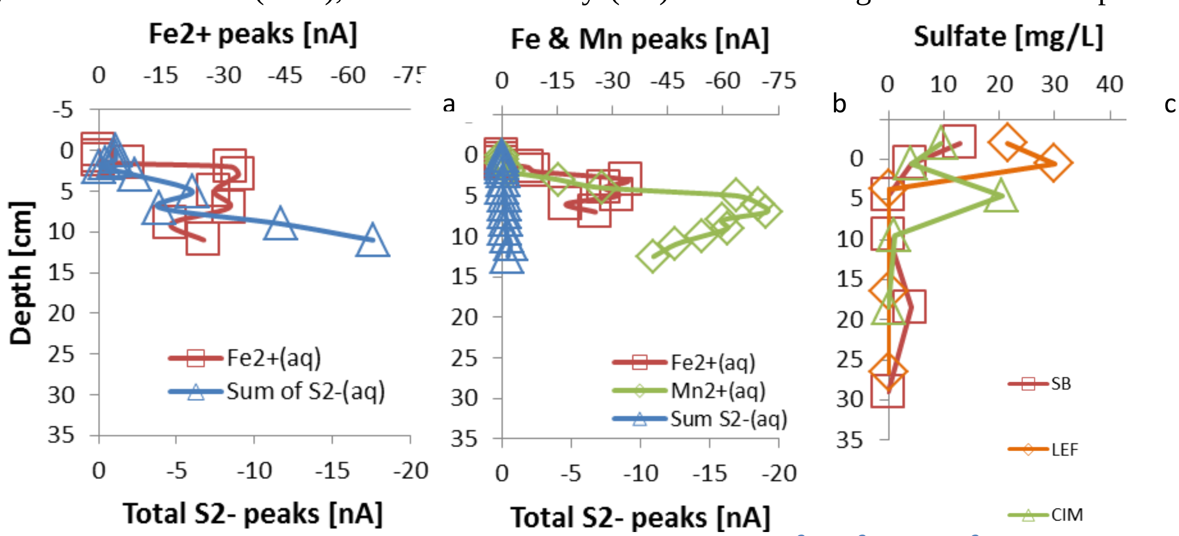

Figure 3 Sediment dissolved species concentration profiles for Mn^{2+}, Fe^{2+}, and ΣS^{2-} for (a) LEF and (b) CIM sites (depth is approximate). (c) SO_4^{2-} concentration profile within all sediment cores.

abundance of porewater constituents (Fe^{2+}, ΣS^{2-}, and Mn^{2+}) in the Lower Estuary Flats and Clay Influenced mouth. Sulfate concentrations detected in the water column (9.5-21.5 mg/L) were consistent with those observed by Berndt and Bavin (2009) upstream in the St. Louis River and Oster (2011) in the Estuary. Although measurements represent only one snapshot in time, no discernable downstream trend of high to low sulfate concentration was observed. Sulfate concentrations initially decrease in the LEF and SB cores while the CIM core had a seemingly anomalous sulfate concentration at 5 cm (20.5 mg/L). Sulfate concentrations in all cores decreased rapidly to below detection limit within 5-10 cm, a trend consistent with active biological sulfate reduction (Figure 3c) in surficial sediment.

Although an accurate measurement of the depth at which porewater measurements were made may have been compromised by malfunctioning micromanipulation, some general conclusions can be drawn. Porewater voltammetry data in Figure 3a and 3b for CIM and LEF, respectively, depict Fe^{2+} magnitudes to be relatively similar with respect to one another at ~-30 nA. Sulfide concentrations in each environment, however, are markedly different, with the LEF core having magnitudes (0 to -17.6 nA) higher than the CIM (-1.8 to -2.4 nA) site (Figure 3a and 3b). The CIM core had a quantifiable amount of Mn^{2+} below 3 cm (Figure 3b). A rapid halt in the increase of dissolved ferrous iron as depth increased suggests that precipitation of iron with sulfide may have been occurring in both environments.

Solid Phase

Depth profiles for acid volatile sulfides (AVS), total sulfur (TS), and total organic carbon (TOC), for SB, CIM, and LEF sites are presented in Figure 4a, b and c. AVS concentrations in the LEF and CIM are relatively low (0.02-0.24 umol/g, separate scale) from 0 to 10 cm depth and increase to a peak of 1.35 and 0.55 umol/g in the LEF and CIM cores, respectively (Figure 4a). The SB core had an AVS peak between 10 and 20 cm that was one to two orders of magnitude greater (22 umol/g) than concentrations in the LEF and CIM (Figure 4a). Due to recent questioning of the AVS method

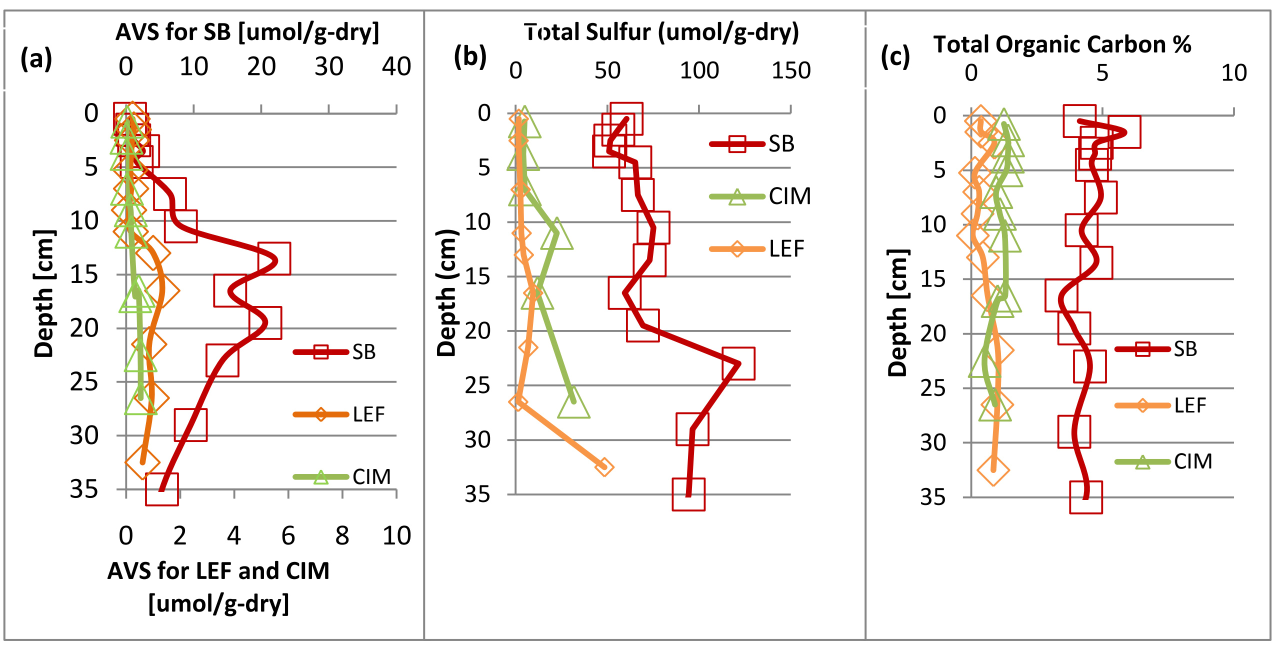

Figure 4 Sediment profiles of (a) AVS, (b) Total Sulfur(TS), and (c) TOC for the LEF, SB, and CIM sites in the St. Louis River Estuary.

(Hammershmidt. 2010), total sulfur (TS) was measured in the three cores to compare with AVS for confirmation relative abundance of sulfur. In all cores, AVS extracted only a fraction of the sulfur (Figure 4a and 4b), likely missing organic sulfur which is not extracted quantitatively in the operationally defined AVS measurement. For example, the SB has noticeably lower AVS concentration throughout the core (0-22 umol/g-dry) (Figure 4a) relative to total sulfur (56-122 umol/g-dry) (Figure 4b). Although TS and AVS measurements target different sulfur fractions, the eneral trend of increased levels of sulfur the in SB relative to the CIM and LEF is observed in both techniques. TOC is depicted in Figure 4c in units of % carbon. LEF and CIM cores had low TOC (0.52% ±0.33 and 1.13% ±0.27) relative to SB core (4.35% ±0.59) along the entire sediment profile. There was no clear trend with depth in dissolved TOC concentrations (30-40 mg/L, data not shown) for any of the cores although the SB has ~5 times more OC relative to the CIM and LEF (Figure 4c).

<u>Mercury and Methylmercury</u>

Depth profiles of Total Mercury (THg), methylmercury (MeHg), and percent methylmercury on the solid phase are depicted in Figures 5a, b, and c, respectively. CIM and LEF cores have lower THg concentrations relative to the LEF core (Figure 5a). Throughout each core, THg concentrations are fairly consistent, with the exception of the LEF site at which substantially higher THg was observed near the sediment surface (Figure 5a). THg concentrations in the fourth site, Upper Estuary Flats, was measured to be consistently ~100ng/g, placing it between the SB and LEF site in terms of total mercury content. MeHg concentrations can be interpreted by simultaneously considering MeHg concentration (Figure 3b) and percent MeHg (Figure 3c). The SB displays a peak MeHg concentration (45 pg/g) between 5 and 10 cm while the LEF core has peak MeHg concentrations near the sediment water interface (79 pg/g). Percent MeHg is a representation of the sediment's ability to convert inorganic Hg to the organic fraction, MeHg (Drott et al. 2008). Both the LEF and SB cores peak between 5 and 10 cm, with values of 0.28% and 0.03%, respectively. In the CIM core, there seems to be no particular trend relative to MeHg or percent MeHg with depth (separate scale).

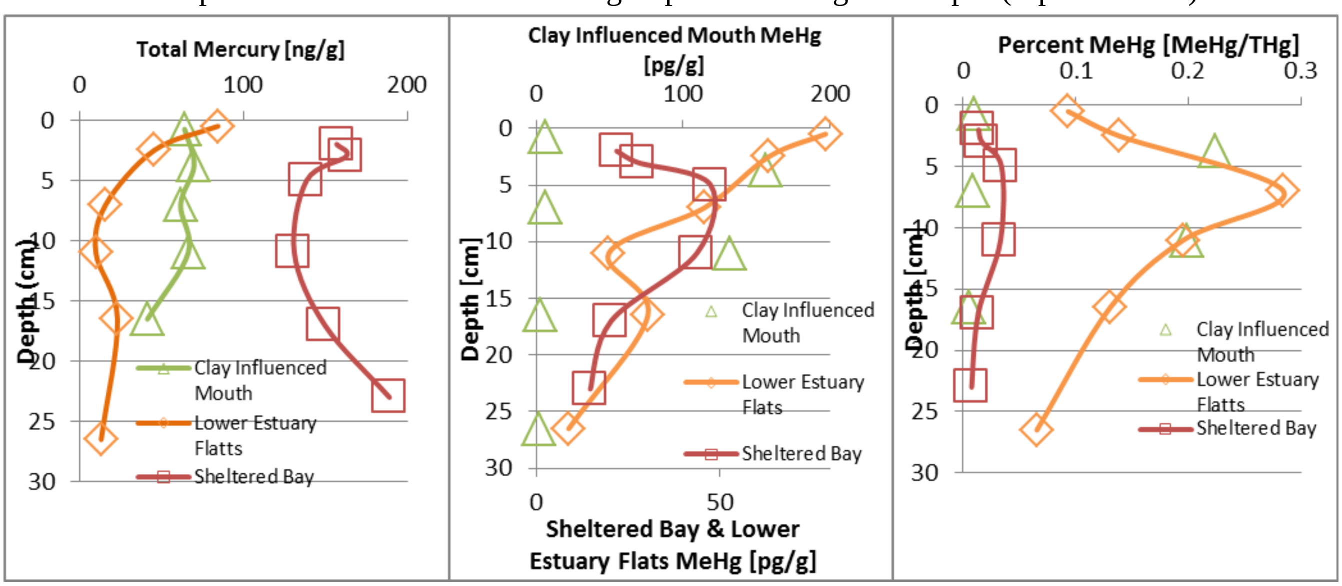

Figure 5. Sediment profiles of (a) Total Mercury (THg), (b) Methylmercury (MeHg), and (c) percent Methymercury (MeHg %) in the solid phase at sites CIM, SB, and LEF.

DISCUSSION

Dissolved Porewater

Porewater sulfate concentrations (Figure 3c) display a similar gradient at each site, from similar overlying water concentrations (10-20mg/L) to below detection limits within 5-10cm. Consumption of sulfate in aquatic sediments is usually by a reduction process mediated by sulfate reducing bacteria in the digenetic process (Sorensen J. and Jeorgensen B. 1987). A conceptual model of the different zones of chemical digenesis is illustrated in Figure 6. Sulfate is the main source of energy to the SRB, while the electron donor is organic matter (Harmon. 2007). A gradient of sulfate from a detectible amount at the sediment water interface to a level below detection limit at a certain depth (between 5-10 cm), such as those in the LEF, CIM, and SB displayed in Figure 3c, can be seen as one line of evidence of sulfate reduction within all sediment profiles (Froelich et al. 1979).

Iron reduction appears to be occurring in both sediment profiles (CIM and LEF), although no quantitative interpretations can be made since a full inspection of the porewater geochemistry has not been conducted (Figures 3a and 3b). The process of iron reduction occurs due to Iron Reducing Bacteria (FeRB) in addition to some secondary redox reactions (Fossing. 2004). Reduced iron species and iron reduction processes are important due to their ability to complex S^{2-} and change the dynamics of sediment diagentic processes (Ulrich and Sedlak. 2010; Froelich et al. 1979). In addition to the complexing of Fe(II) and S(II) to form insoluble FeS solids, FeRB are able to suppress the ability of SRB to reduce sulfate since Fe (III) reduction is more favorable thermodynamically (Froelich et al. 1979). Dissolved ΣS^{2-} is a byproduct of sulfate reduction by SRB within sediment porewater. The LEF site shows ΣS^{2-} concentrations begin to increase (Figure 3a and 3c) near the same region that sulfate concentrations decline to zero, which is located 5 cm below the sediment water interface (SWI). Depths at which sulfate is being consumed and sulfide (or other reduced sulfur species) is being produced gives greater evidence of active biological sulfate reduction in surficial sediment (Hammerschmdt, 2004). Although it appears that both iron and sulfate reduction are occurring, the lack of complete a voltammetry dataset in conjunction with one point calibrations and bending electrodes, limits the utility of data presented in Figure 3a and 3b. Although the dataset is not complete, it can be inferred that the transition from iron(III) reduction to sulfate reduction occurs in the top 10 cm of sediment in the St. Louis River estuary in all habitat zones.

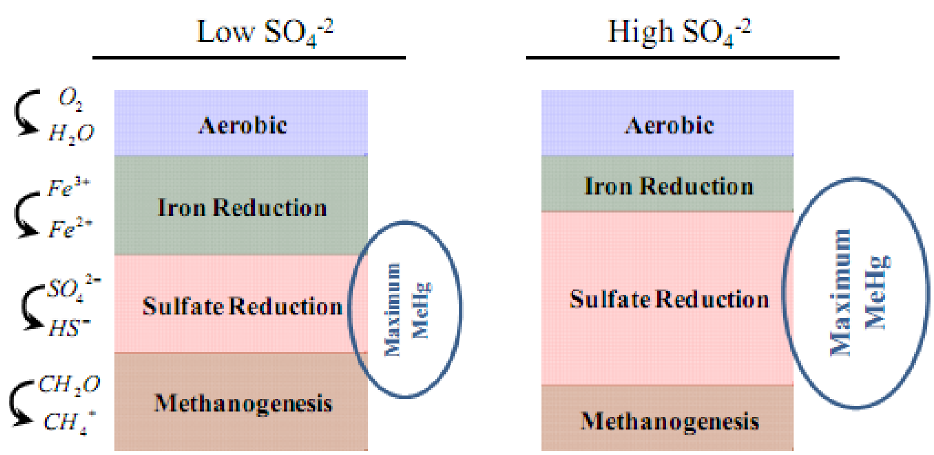

Figure 6. Conceptual model of recent sediment diagensis for oxygen, iron, sulfur and methanogenesis related to methylmercury production. The salmon colored sulfate reduction zone traditionally is associated with methylmercury production, represented by blue circlies (adjacent to suflate reduction zone).

Solid Phase

AVS measurements (Figure 4a) represent another possible line of evidence of SRB presence, since it is a measure of reduced sulfur (Brouwer. 1994). Although AVS is an indicator of SRB presence, it may not give the current depth at which SRB are actually metabolizing sulfate. Since AVS does measure some stable FeS species (such as pyrite), sulfides that had already been produced, complexed and deposited, may represent historical sulfide sinks. Additionally, AVS methods do not quantitatively extract organic sulfur species which could explain the large fraction of total sulfur at shallow depths where little AVS was found. AVS shows that there is likely more sulfate reduction occurring in the SB sites by at least one order of magnitude (Figure 3a) relative to the LEF and CIM sites. Increased sulfate reduction can be enhanced by two factors in the estuary. The first, which agrees with the conceptual model of a decreasing sulfate gradient along the St. Louis River estuary, is higher sulfate concentrations lead to increased SRB activity (Gilmour et al. 1992), as long as sulfides do not build to an inhibitory level (Hammershmidt et al. 2004; Benoit et al. 1999). Increased SRB activity leads to a greater reduced sulfur sink, which is represented in figure (4a) as higher AVS in the SB site. The other factor that facilitates increased microbiological activity is higher organic carbon concentrations in the sediment. Figure 4c shows that sediment TOC is five times higher in the SB in comparison to the LEF and CIM sites. OC is thought to be the electron donor in the terminal electron transfer to sulfate in the reduction process (Harmon et al. 2007). The combination of higher TOC and sulfate in the upper estuary manifests itself as higher microbial sulfate reduction in the SB site while lower sulfate and TOC are limiting in the LEF and CIM sites. Although quantitative measurements of particle size were not made during this phase of the study (planned for Phase II), it is inferred from qualitative observations that the SB contained substantially more fine grained material than either CIM or LEF environments.

TS was measured primarily as a verification of AVS as a sink of sulfur in the sediment profile (Figure 4a and 4b). Although in the uppermost sediment profile of SB (0-10 cm), AVS missed a fraction of sulfur that TS did measure, it is likely not a reduced species that would indicate sulfate reduction. Also, the peak of TS has been shifted down slightly (20-25 cm) in the SB site relative to the AVS peaks (15-20 cm) but the other sites (LEF and CIM) had similar peak depths for AVS and TS (10-15 cm). TS does measure more recalcitrant fractions of sulfur such as FeS_2 (Pyrite) and organic sulfur, which could be more prevalent in historical sulfur deposition/reduction.

Mercury and Methylmercury

The mercury and methylmercury concentrations in the St. Louis Estuary (Figure 5a, 5b, and 5c) need to be interpreted in light of other biogeochemical evidence. MeHg and percent methylmercury (MeHg%) are not the largest in the sediment that has the greatest amount of reduced sulfides (the Sheltered Bay); instead MeHg% is the greatest in the sediment location of the lowest TOC (Figure 4c) and AVS (Figure 4a). This suggests that methylation may have been occurring more efficiently at this site. MeHg in the Clay Influenced Mouth has no discernable pattern throughout the sediment core with concentrations spiking in multiple areas (Figure 5b and c). Based on this limited Phase I data, it is difficult to explain why there are deviations from the expected higher production of MeHg in areas with higher sulfate and organic matter. It is possible that the St. Louis River Harbor sulfate levels have already reached a point in which they are not limiting; however, more investigation needs to be conducted to fully understand the relationships between methyl mercury and organic carbon and sulfate in this freshwater estuary system.

CONCLUSIONS

There is strong evidence that sulfate reduction is occurring within surface sediment (0-10cm) in all habitat zones of the St. Louis Estuary (Figures 3 and 4). There is a clear difference between the amount of sulfate reduction occurring between the SB site and LEF/CIM sites (Figure 4a) which may be related to the sulfate gradient in the St. Louis Estuary (Berndt and Bavin 2009; Oster 2010) and/or higher organic carbon concentrations. Although there is evidence that there is varying sulfate reduction in the St. Louis River Estuary sediment, more detailed investigation of the sediment redox environment will need to be conducted to fully understand the reasons for the variability.

Since there is strong evidence of sulfate reduction in surficial sediment (Figures 3a, 3b, and 4a), it is likely that mercury methylation is also occurring in surficial sediments (Compaeu et al. 1985). The main conclusion that can be made from this initial phase study is that although major differences in sediment geochemistry exist, all zones in the estuary seem to have the potential to methylate mercury. More investigation is needed to parse out details regarding the factors most important for mercury methylation in the St. Louis River Estuary.

FUTURE WORK

Phase II of this study has received funding and is planned for the next field season. The work that was performed during the first year identified differences in sulfate reduction amongst habitat zones and will inform experimental design during the second year. Although a clear relationship between sulfate loading and mercury methylation has been observed in experimental wetland in Northern Minnesota, the extent to which sulfate limits MeHg production in lake/river environments is not well known (Jeremiason, J. D., Engstrom, D. R., et al 2006; Engstrom personal communication. 2011). The objective of Phase II of the project will be to investigate the relationship between sulfate loading and mercury methylation in the St. Louis River Estuary.

First, a more thorough characterization of in-situ geochemistry will expand the first year's work by obtaining complete sediment profiles that include DOC, ΣS^{2-}, Mn^{2+}, Fe^{2+}, O_2, pH, TOC, AVS, Total Mercury (THg), and Methylmercury (MeHg) in each of four habitat zones. Sediment coring techniques and sample analysis will be replicated from the methods that were used in during the first year.

The major initiative for Phase II will include obtaining intact box cores from the same four SLRA Aquatic Habitat Zones. These cores will be placed in custom fabricated microcosm containers for sulfate amendment experiments. Sediment from the four different environments will be exposed to three treatments each, a control, low sulfate, and high sulfate treatment. These experiments will be run for 4-6 months, which should allow sufficient time for sulfate from the overlying water to diffuse into sediment and influence SRB and other bacterial populations. During this time, periodic redox profiles will be taken to non-destructively obtain in-situ, dissolved ΣS^{2-}, Mn^{2+}, Fe^{2+}, pH, and O_2 using voltammetry. Sediment sub-cores will also extracted and sacrificed at the beginning and end of the incubation for THg and MeHg solid phase analysis. Results of this study will help illuminate whether methylmercury production is limited by sulfate in this freshwater estuary system.

ACKNOWLEDGEMENTS

The authors would like to thank the Minnesota Water Resources Center and the Minnesota Department of Natural Resources Division of Lands and Minerals for jointly providing financial support for this effort.

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Quantifying differential streamflow response of Minnesota ecoregions to climate change and implications for management

Basic Information

Title:	Quantifying differential streamflow response of Minnesota ecoregions to climate change and implications for management
Project Number:	2010MN270B
Start Date:	3/1/2010
End Date:	2/1/2011
Funding Source:	104B
Congressional District:	4
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Climatological Processes, Agriculture
Descriptors:	None
Principal Investigators:	Christian F Lenhart, John Nieber

Publications

1. Lenhart, C., J. Nieber, H. Peterson, and M.Titov. Differential Response of Midwestern Watersheds to Climate Change and Implications for Management. Part of a workshop, “The Role of Ecological Restoration in Climate Change Adaptation for the Midwest”. Society for Ecological Restoration-Midwest Great Lakes Chapter Annual Meeting Program, Pg. 6. SER-MWGL: Springfield, IL. April 1 to 3, 2011.
2. Lenhart, C., J. Nieber, and H. Peterson. 2010. From the Cornbelt to the North Woods; Understanding the Response of Minnesota Watersheds to Climate Change. Water Resources Center Climate Summit, Minnesota Landscape Arboretum, Chanhassen, MN. September 2010.
3. Lenhart, C., H. Petersen, and J. Nieber. 2011. Increased Streamflow in Agricultural Watersheds of the Midwest: Implications for Management. Watershed Science Bulletin, Spring 2011.
4. Nieber, J. Stream Flow Trends in Minnesota. University of Minnesota. University of Minnesota WRS graduate student welcome weekend, Cloquet, MN. November 2010.
5. Lenhart, C., and J. Nieber. Quantifying Differential Streamflow Response of Minnesota Ecoregions to Climate Change and Implications for Management. USGS Minnesota Water Science Center. March 2011.
6. Lenhart, C., J. Nieber, and H. Peterson and M. Titov. Differential Response of Midwestern Watersheds to Climate Change and Implications for Management. Part of a workshop, "The Role of Ecological Restoration-Midwest Great Lakes Chapter Annual Meeting, Springfield, IL. April 2, 2011.

Quantifying differential streamflow response of Minnesota ecoregions to climate change and implications for management

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Funding Source: USGS-WRRI 104B/CAIWQ Grants Program

Project Duration: 3/1/10-2/28/11
Reporting Period: 3/1/10-2/28/11

1) Research

Background

There is a growing need to understand the extent to which changing streamflow regimes in the Upper Midwest are caused by land use vs. climatic changes as there have been dramatic increases in flow in many Upper Midwestern streams. As watershed mangers plan to address water supply needs, cope with flooding issues, maintain healthy aquatic ecosystems, and meet water quality standards, it is imperative that appropriate adaptation measures be considered for implementation. Climate change adaptation decisions will largely be based on existing data and hydrologic models. Global Climate Models (GCMs) generally predict increased variability in weather, in particular more frequent extreme storm events and droughts. In the Midwest and Great Lakes projections from the Intergovernmental Panel on Climate Change (IPCC 2007) suggest that lake and river levels will be lower due to increased evaporation caused by higher temperatures. Increased precipitation may counter increased evaporative potential in some areas, as well as changes to other components of the hydrologic cycle.

The net impact on water availability and quality may vary considerably by region within the upper Midwest. Changes in the timing, intensity and duration of precipitation will determine exactly how climate change affects water quantity and quality. For this reason and due to variability in local geology and land-cover the hydrologic response of specific Midwestern ecoregions to climate change will not be monotypic. Some reported research results indicate that increased rainfall in recent decades in the agricultural watersheds of the Upper Midwest have actually resulted in increased baseflow (Zhang and Schilling 2006) and less variability in streamflow at most flow levels. Whether this increase in flow is really in response to increased rainfall, or maybe that it might also be in response in landuse/land cover change is a an important question that needs to be addressed.

While flooding is the most publicized impact of changing hydrology and climate (Mutel 2010), watersheds respond to greater precipitation in a variety of ways including the potential alteration of all components of the water budget . Evapotranspiration (ET), groundwater recharge and interception may all be altered, all potentially influencing streamflow. Therefore it is necessary to examine the interactions of all components of the hydrologic cycle to understand how watersheds may respond to precipitation increases:

Purpose

This study was conducted to learn from recent hydrologic response to climate changes in order to better understand potential future watershed response to climate changes. This assumes that the near future hydrologic response will be similar to recent response to climate changes, or at least that there is much to be learned from recent responses. A second major goal was gaining an understanding of the differences in watershed response to climate change between northern forested watersheds and agricultural watersheds in the upper Midwest. Lastly, the identification of hydrologic and water quality management issues related to climate and ongoing land-use changes was a major goal.

Research Questions

Four hypotheses were examined in this study: 1) The hydrologic response of forested watersheds in the upper Midwest to precipitation increases is different than tile-drained, row-crop-dominated watersheds; 2) Increased streamflow in southern Minnesota and portions of adjacent states (Iowa, Wisconsin and the eastern Dakotas) is mostly from land-use and land cover changes rather than precipitation increases (although they contribute as well); 3) There have been important changes in the hydrologic regime such as increased baseflow and streamflow volume aside from increased flooding.; 4) Response to precipitation increases in the near future will be similar in the immediate future (<20 years) to the recent past. Of course, in the long term of 20^+ years, if the extreme climate change scenarios with the greatest temperature and precipitation changes occur, the response may be very different.

The first 3 hypotheses were explicitly addressed by our hydrologic data analysis and modeling work. The 4^{th} hypothesis was partially addressed through modeling of increased precipitation using the Soil, Water, Atmosphere, Plant (SWAP) model.

Methods and approach

We employed a variety of methods to characterize watershed response to precipitation increases in an effort to better understand the impacts of land-use, drainage and climate change on streamflow. The hydrologic analysis portion of the study focused on characterizing recent hydrologic responses over the past few decades to better understand the near-future response to climate changes, focusing on the effect of increased precipitation. The major strength of this approach is the use of actual data and therefore hydrologic response are known with certainty, unlike a modeling approach. A weakness of this approach is that there is uncertainty as to what degrees the future will be like the present, although it is safe to assume that the same basic hydrologic processes will be at work at least in the early stages of climate change. However, different rates of hydrologic processes are likely to occur potentially causing unpredictable effects on ecosystems and humans.

The applications in this report are divided into three parts. In Part 1 USGS streamflow and precipitation data were analyzed to evaluate changes in streamflow response over time. In Part 2 changes to hydrologic processes were examined using the ratio between streamflow and precipitation (Q:P ratio). The hydrologic processes involved in generated watershed runoff were modeled in Part 3 to assess the hydrologic response to precipitation changes and landuse/landcover changes using the physically-based Soil, Water, Atmosphere, and Plant (SWAP) model.

The Indicators of Hydrologic Alteration (IHA) software was used to examine recent changes in streamflow regime in the upper Midwest (Richter et al. 1996). The IHA is designed to identify changes in hydrologic regime that may be important for aquatic ecology, water quality and sediment transport beyond simple measures of peak flow that are often the focus of hydrologic studies. The IHA calculates a total of 67 statistical parameters which are subdivided into two groups, the IHA parameters and Environmental Flow Components (EFC). The IHA parameters include metrics of streamflow magnitude, duration, frequency, timing and rate of change. The EFC are of particular ecological importance and included metrics on low flows, extreme low flows, high flow pulses, small floods, and large floods. IHA parameters were calculated using non-parametric (percentile) statistics because hydrologic datasets tend to be skewed and thus do not meet the normality requirements of parametric statistics.

This suite of hydrologic statistics is used to compare changes to the above metrics before and after a given time period. The time periods 1940-1979 and 1980-2009 were compared in this study. Most stream gauge records in Minnesota do not start until 1940 or later. The year 1980 was chosen as the dividing point to compare pre-impact to post-impact hydrology. The year 1980 was selected because the indicators of climate change began appearing at that time and subsurface tile drainage began expanding rapidly in Minnesota around that time. Significance testing was done by re-shuffling the existing data to obtain a larger sample size, similar to boot-strapping procedure.

Land cover estimates were obtained from the U.S. Natural Resource Conservation Service's rapid watershed assessment reports for purposes of comparison. Watersheds were grouped into three categories: primarily agriculture (>66% agriculture), mixed use: (33-67% agriculture) and forested: (<33 % agricultural cover).

Assessment of hydrologic processes was examined through changes in the discharge to precipitation (Q:P) ratio. Twenty-five watersheds with varying drainage areas and land use/land cover located across Minnesota and neighboring states were selected based on the availability of long-term stream flow data (**Error! Reference source not found.**). Discharge to precipitation (Q:P) ratios were calculated for these 25 watersheds using monthly, seasonal and annual data. Discharge data, which is a combination of both groundwater discharge and surface water runoff, was obtained through the USGS Surface Data for Minnesota website (USGS, 2010). Any lapse in available streamflow data is indicated in Table 1. Precipitation data for the climate divisions overlapping the six analyzed Minnesota River Basin watersheds was obtained through the Western Region Climatic Center (WRCC, 2010). To address those watersheds which overlapped several climate divisions, mean monthly and annual precipitation was calculated using the Thiessen polygon method. To obtain a dimensionless ratio, precipitation was then converted to a volume by using the area of each watershed.

To further study the significance of the variation between time intervals and pin-point which season these variations in Q:P ratios was occurring, a more detailed seasonal Q:P analysis was completed using a Mann-Whitney test. The Mann-Whitney test is the non-parametric alternative to the unpaired student t-test and will identify whether the two time periods have the same distribution of Q:P ratios. This seasonal analysis was completed to identify the variation within each season independently using each included years seasonal Q:P ratios rather than just one mean for each time interval. Seasons were defined as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and fall (September, October, and November).

SWAP modeling was done to compare the hydrologic response of two different sites, a forested watershed near Marcell, Minnesota and tile-drained row-crop agricultural watershed at the Waseca Experiment Station of the University of Minnesota. SWAP is a field-scale physically-based model that simulates the interactions of precipitation, infiltration and groundwater discharge, surface runoff, plant interception, transpiration and evaporation. At these two locations a variety of plant covers and climate change scenarios were examined. Perennial prairie grasses, corn and soybeans were modeled at Waseca while deciduous and conifer tree cover were modeled at the Marcell forest. Rainfall increases of 10 and20% were also examined to better understand future hydrologic response to predicted rainfall increases in the region. The SWAP modeling exercise was used to evaluate the effect of land cover type and precipitation variability on total runoff (surface plus subsurface). This was done to help address the question about what is the relative influences of precipitation and landuse/land cover on streamflow. The data analyses in Parts 1 and 2 point to a significant response to these changes, but the use of the SWAP model can provide a mechanistic basis to the assessment of watershed response sensitivity to these changes.

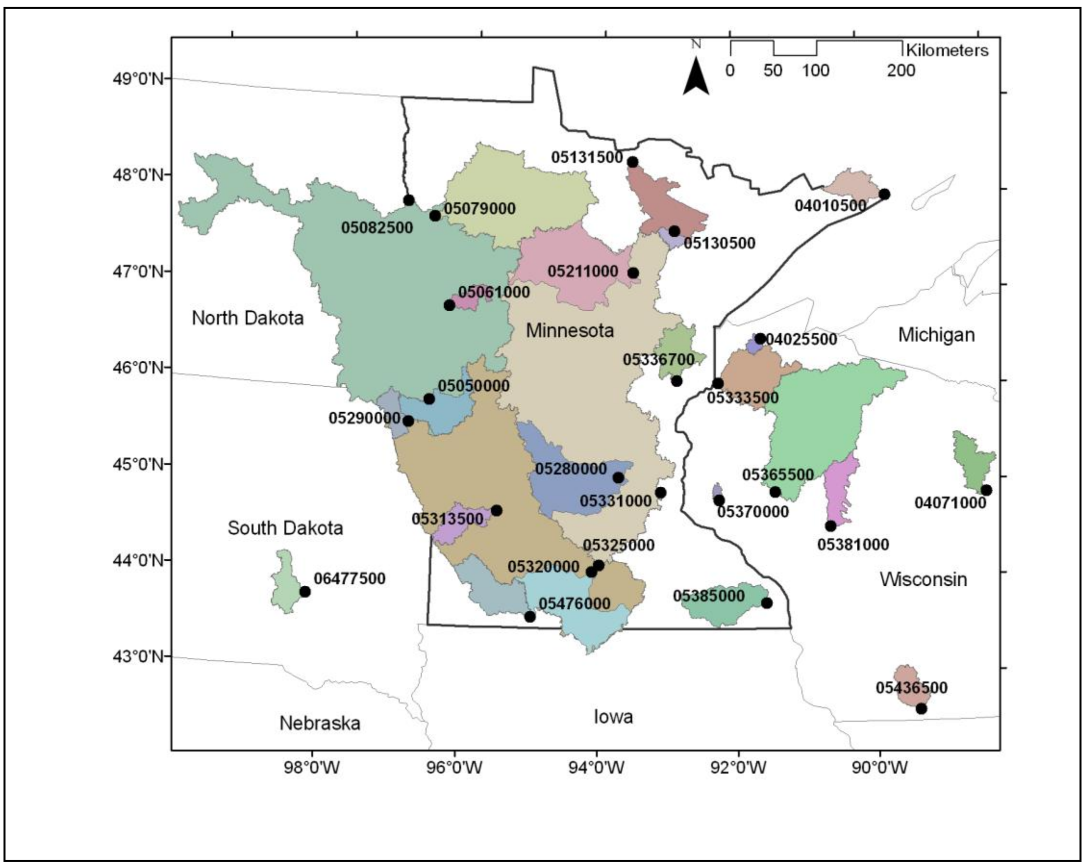

Figure 1. **W**atersheds and associated USGS streamflow gauges analyzed in this study. 16 of the above 25 were analyzed using IHA, while the Q:P ratio was assessed for all of the above sites.

Results

1. Hydrologic analysis of recent trends IHA analysis

Summary data on changes to the magnitude and variability of streamflow including mean annual flow, coefficient of variation, median monthly flows and low flow are shown in Table 1. Overall, there was significant increases in many of the streamflow variables measuring magnitude and duration for most flow levels below the small flood (2 year recurrence interval) flow in the agricultural watersheds that have more than >67% agricultural land cover. In contrast the forested watersheds of northern Minnesota and Wisconsin had very few significant changes despite slight increases in the average annual precipitation over the 1980-2009 time period. The greatest change in the north was in the winter low flows, probably due to more frequent and earlier snowmelt.

The annual water yield, an indicator of total stream flow volume and measured as mean annual flow increased in all southern agricultural watersheds. In contrast, mean annual flow either decreased or did not increase significantly in the northern forested watersheds, despite the increase in winter low flows. Declines to high flows brought down the mean annual flow in the northern forested watersheds.

By month, the greatest median flow increases by percentage were during the low flow season between fall and winter for almost all sites . Overall southern agricultural sites increased more, with monthly increases ranging from 120-260%. Median flows declined or did not increase significantly in northern forested watersheds, particularly during the typical high flow period of April to August. Streamflow did increase significantly during the winter low flow months (November – February).

In the southern agricultural watersheds, almost all flow duration metrics (1-day, 3-day,7-day, 30-day and 90-day minimum and maximum) have shown increasedflows. In the northern forested watersheds, the low flow levels have increased, while high flow levels have decreased at most sites when comparing the last three decades to the previous few decades.

No consistent geographic trends were found in the rise and fall rate of discharge on hydrographs in response to storm events. However, many of the individual watersheds did have significant changes in rise and fall rates, measured as the mean flow rate change/day, particularly sites in the Minnesota River Basin. Surprisingly many of the larger watersheds (>10,000 km^2 area) became flashier, with significant increases in the rise rate. For example the rise rate of the Minnesota River increased by 140%, while the Red River at Grand Forks, MN increased 80%. All three Minnesota River basin streams (Blue Earth, Minnesota and Yellow Medicine) had significant increases in both the rise and fall rate, while other regions had more mixed results. The Sugar River and Oconto River of Wisconsin were the only rivers to have significant decreases in both rise and fall rates.

Amongst flow indicators of ecological significance (EFCs), there was a general increase in winter low flows (the mean discharge of low flows occurring in each month; a similar metric to baseflow) for many northern forested watersheds. In contrast, southern agricultural watersheds, like the Minnesota River experienced significant low flow increases in most months, except March, April and May (Fig. 4). During winter (October-February) low flows increased by a factor of 2 to 3 times in the Minnesota River. The high flow metric (75%-100% flow) peak and duration did increase at many southern agricultural sites. Small and large flood peaks (2 yr and 10 yr recurrence interval) had significant increases at only 6% and 11% of sites with no consistent trends across regions.

Streamflow variability actually decreased at 15 of the 16 sites as measured by the coefficient of variation largely because of the increases in low flow across most sites.

Table 1. Summary data for the IHA analysis for 16 watersheds in the Upper Midwest. Change in flow for the 1980-2009 time period is compared to the 1940-1979 time period by percent (%) change in magnitude or number of months with significant change.

Station location	USGS gauging station #	Predominant land-use category	% change in mean annual flow	% change in coefficient of variation	% of 12 months with a median monthly change *	% of 12 months with a low flow change*
Blue Earth River at Mankato, MN	5320000	>67 ag	73%	-29%	83%	42%
Bois Brule at Brule, WI	4025500	>67 % forest	-2%	-13%	92%	17%
Buffalo River at Hawley, MN	5061000	mixed	42%	-7%	67%	67%
Chippewa River at Chippewa Falls, WI	5365500	>67 % forest	-7%	5%	8%	-42%
Des Moines at Jackson, MN	5476000	>67 ag	100%	-26%	83%	50%
Little Fork River at Little Fork, MN	51315000	>67 % forest	-8%	-14%	42%	42%
Little Minnesota River at Peever, SD	5290000	>67 ag	27%	-33%	100%	100%
Minnesota River at Mankato, MN	5325000	>67 ag	75%	-23%	92%	75%
Mississippi River at St. Paul, MN	5331000	mixed	31%	-11%	50%	33%
Mississippi at Grand Rapids, MN	5211000	>67 % forest	4%	-7%	0%	0%
Oconto River at Gillett, WI	4071000	>67% forest	-9%	-11%	0%	8%
Pigeon River at Grand Portage, MN	4010500	>67 % forest	-9%	-13%	33%	33%
Red River at Grand Forks, ND	5082500	>67 ag	56%	-10%	75%	33%
Red Lake river at Crookston, MN	5079000	>67 ag	6%	-6%	17%	8%

Root River near Houston, MN	5385000	mixed	57%	-36%	100%	83%
St. Croix River at Grantsburg, WI	5333500	>67 % forest	-6%	-7%	0%	0%
Sugar River at Brodhead, WI	05436500	>67 ag	29%	-32%	92%	100%
Yellow Medicine at Granite Falls, MN	05313500	>67 ag	77%	-38%	92%	58%
* Significant at 0.05 level, determined by re-shuffling of the statistical population in a boot-strapping-like approach used in the IHA software.						

2. Assessment of change to Hydrologic Processes:

Results of the Mann-Whitney analysis indicated that 17 of the 25 watersheds had variations in Q:P ratios between 1950-1979 and 1980-2008 when comparing seasonal averages . The seasonal analysis was completed by looking at each year's seasonal Q:P ratio individually for both time periods, 1950-1979 (n=28) and 1980-2008 (n=29). For those watersheds that had statistically significant differences in seasonal Q:P ratios during 1980-2008 compared to 1950-1979, nearly each change was an increased ratio during the 1980-2008 period. Only three watersheds had summer Q:P ratio variations and each was located within the Red River Basin with an increase during the 1980-2008 time period.

Gauging station 5365500- Chippewa River at Chippewa Falls, Wisconsin was the only station with a significant decrease in Q:P ratio in the winter and is a predominantly forested watershed. Gauging station 4071000- Oconto River near Gillett, Wisconsin was the only station with a significant decrease in Q:P ratio in the spring and is also predominantly forested. Neither of these two stations had any other significant variations in Q:P ratios; however, they did have decreasing ratios for each season.

Gauging station 5436500-Sugar River near Brodhead, Wisconsin was the only station with a significant decrease in Q:P ratio in the fall; however, the other three seasons had increasing ratios that were not statistically significant. It is predominantly cultivated crop and grain; therefore the change variation may be due to a variation in the streamflow timing.

Two forested watersheds located in northeast Minnesota 5130500 and 5131500 had significant increases only during the winter season. During the summer months, although not significant, Q:P ratios decreased. This could perhaps be due to snowmelt occurring earlier.

As referenced previously, Station 4071000- Oconto River near Gillett, Wisconsin is a predominantly forested watershed with decreasing seasonal Q:P ratios and results indicated overall mean annual Q:P ratios have also significantly decreased during 1980-2008. In order to get an idea of how the mean annual Q:P ratios are varying across the state, regardless of statistical significance, Figure 2illustrates whether the 1980-2008 ratio increased or decreased compared to 1950-1979. The break between significant change corresponds to the ecoregion or land cover with the forested regions of northern Minnesota and Wisconsin generally experiencing no significant change.

The Mann-Whitney test was also used to analyze annual variations between the 1950-1979 and 1980-2008 time intervals. Annual Q:P ratios were significantly different between time intervals for 8 of the 25 watersheds (Table 2, Figure 2). The watersheds with significant increases during 1980-2008 were all located within the Minnesota River Basin or the Karst region of Southeast Minnesota (5385000- Root River near Houston, MN) and using the 2001 National Landcover Dataset (Horner et al, 2004) most of them have higher intermittent drainage density (**Error! Reference source not found.**). This may be an indicator of drainage ditches used to capture the discharge from tile drainage of the agricultural fields.

As referenced previously, Station 4071000- Oconto River near Gillett, Wisconsin is a predominantly forested watershed with decreasing seasonal Q:P ratios and results indicated overall mean annual Q:P ratios have also significantly decreased during 1980-2008.

Overall, results indicated that Q:P ratios are increasing in Upper Midwest watersheds that are not predominantly forested. The reason for this seems to be due mostly to land-use change (increasing row crop coverage in replacement of pasture and perennial crops) and increased tile drainage. Increasing precipitation is also a contributing factor, but to what extent is uncertain. While the non-forested regions had greater precipitation increase, the amount that the Q:P ratios increased is too disproportionate to reflect solely the influence of precipitation. Results indicate that changes in Q:P ratios vary by land use, or more regionally defined by ecoregions.

Table 2: USGS gauge stations used in Q:P analysis

USGS gauging station	Station location	Drainage area km^2	Mean annual discharge $m^3 \cdot s^{-1}$		Mean annual precipitation $m^3 \cdot s^{-1}$		Annual Q:P		p-value
			1950-1979	1980-2008	1950-1979	1980-2008	1950-1979	1980-2008	
4010500	Pigeon River at Middle Falls near Grand Portage, MN	1577.3	14.8	13.3	35.9	36.0	0.41	0.37	0.20
4025500	Bois Brule River at Brule, WI	305.6	4.9	4.8	7.7	7.8	0.66	0.62	0.33
4071000	Oconto River near Gillett, WI	1825.9	16.1	15.3	45.2	46.1	**0.36**	**0.33**	0.03
5050000	Bois De Sioux River near White Rock, SD	3004.4	2.2	5.0	56.8	60.1	**0.04**	**0.08**	0.01
5061000	Buffalo River near Hawley, MN	841.7	2.1	3.0	14.9	15.9	0.14	0.18	0.08
5079000	Red Lake River at Crookston, MN	13649.2	40.2	40.3	259.1	271.1	0.15	0.14	0.71
5082500	Red River of the North at Grand Forks, ND	68116.7	93.7	128.1	1157.0	1241.2	0.08	0.10	0.12
5130500	Sturgeon River near Chisholm, MN	484.3	3.5	3.4	10.8	10.9	0.32	0.31	0.71
5131500	Little Fork River at Littlefork, MN	4351.2	32.2	29.9	94.4	95.4	0.34	0.31	0.38
5211000	Mississippi River at Grand Rapids, MN	8728.3	39.7	39.5	178.5	182.2	0.22	0.21	0.69
5280000	Crow River at Rockford, MN	6837.6	21.4	33.8	150.3	160.3	**0.14**	**0.21**	0.01
5290000	Little Minnesota River near Peever, SD	1157.7	1.2	2.0	18.3	21.1	0.06	0.09	0.17
5313500	Yellow Medicine River near Granite Falls, MN	1691.3	3.4	5.6	33.8	36.9	**0.10**	**0.15**	0.04
5320000	Blue Earth River near Rapidan, MN	6241.9	22.8	40.8	143.4	160.7	**0.15**	**0.25**	0.01
5325000	Minnesota River at Mankato, MN	38590.8	90.7	158.4	790.2	864.8	**0.11**	**0.18**	0.00
5331000	Mississippi River at St. Paul, MN	95311.6	351.9	456.7	2019.9	2163.2	0.17	0.21	0.06
5333500	St. Croix River near Danbury, WI	4092.2	39.8	37.6	102.8	105.0	0.39	0.36	0.12
5336700	Kettle River below Sandstone, MN	2248.1	20.4	19.3	51.9	55.3	0.38	0.35	0.37
5365500	Chippewa River at Chippewa Falls, WI	14633.4	145.5	139.5	370.8	378.7	0.39	0.37	0.41
5370000	Eau Galle River at Spring Valley, WI	165.8	0.9	1.0	4.1	4.5	0.21	0.23	0.51
5381000	Black River at Neillsville, WI	1939.9	16.0	18.0	49.6	50.6	0.32	0.35	0.29
5385000	Root River near Houston, MN	3237.5	19.0	30.3	78.8	88.2	**0.24**	**0.33**	0.00
5436500	Sugar River near Brodhead, WI	1354.6	9.8	11.9	34.6	38.3	0.28	0.31	0.18
5476000	Des Moines River at Jackson, MN	3159.8	7.5	16.5	64.1	71.4	**0.11**	**0.22**	0.00
6477500	Firesteel Creek near Mount Vernon, SD	1349.4	0.6	1.1	24.9	27.0	0.02	0.04	0.12

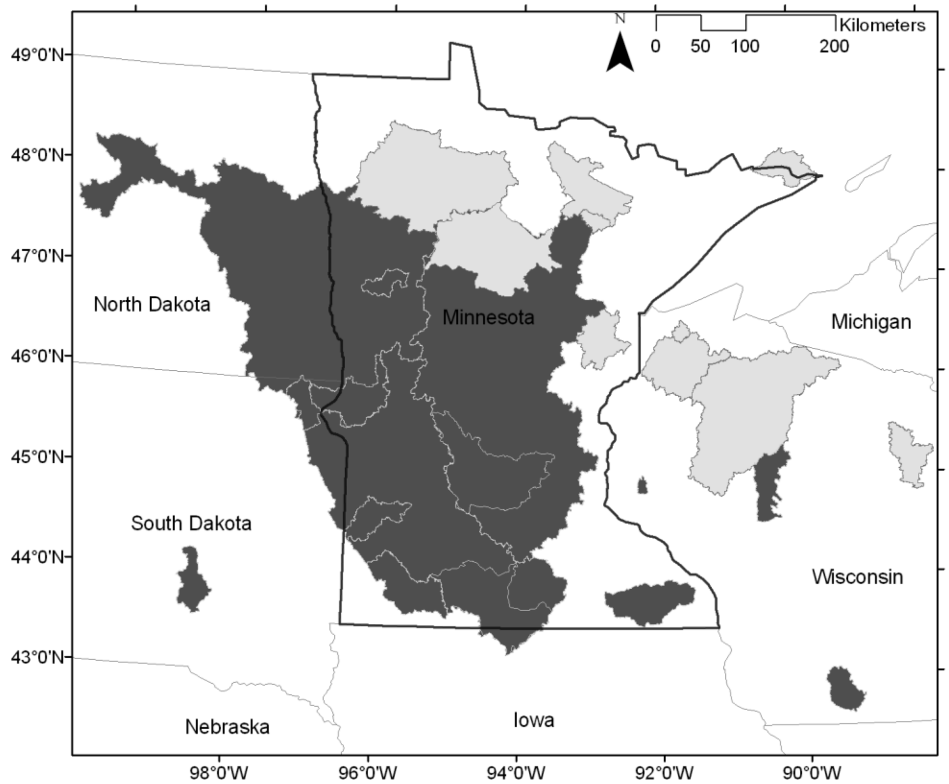

Figure 2. Watersheds darkly shaded signify those with an increase in the Q:P ratio during 1980-2008 when compared to the 1950-1979 time interval. Ratios within the forested watersheds appear to be decreasing while agricultural watersheds in the prairie or savanna regions of southern, central and western Minnesota are increasing. The boundary between forest and former prairie regions runs roughly in a diagonal line across Minnesota from the northwest to the southeast.

3. SWAP modeling

The previous sections dealt with the use of hydrologic, meteorologic, and landuse data to assess the effect of landuse change and climate change on streamflow measures. A supporting line of evidence for the findings presented in those sections is based on the use of physically-based hydrologic models to evaluate the sensitivity of watershed runoff response to climate and landuse changes. The physically-based soil hydrology model, SWAP (Kroes et al., 2009) was applied for this purpose. SWAP was designed primarily for field scale application where conditions can be represented by a single vegetation, single soil type, and single drainage type and therefore does not deal with the spatial variation of landuse, soil types, etc. within a single model simulation.

The SWAP model performs the simulation of the water balance in a soil column in the field, accouting for precipitation, evapotranspiration, infiltration, surface runoff, soil water redistribution, and deep percolation. It does have the ability to handle tile drainage and open ditch drains through a lateral flow function algorithm.

The application of SWAP was intended to assess the sensitivity of the water balance in a field based on the type of vegetation and the magnitude of annual precipitation. The effect of vegetation type such as row crops (corn), prairie grasses, and trees was examined with the idea to evaluate the effect of changes in vegetative cover type. The model was also applied to examine the effect of increased annual precipitation on watershed flow response.

Two geographical locations in Minnesota were used as reference sites to test the effect of vegetation on mean annual runoff. One of the sites corresponds to Waseca, Minnesota, where the landuse practices are largely dominated by agricultural production. For this site simulations were conducted to test the difference in mean annual runoff between annual crop land cover and two species of perennial grass covers. One of the two grass species was a deep-roots prairie grass. The other site was in the north central forest region of Minnesota at the Marcell experiment forest located just north of Grand Rapids. Two types of trees were considered for this location, spruce (evergreen) and a hardwood (deciduous). In the simulations the types of soils that are characteristic of the sites were used to specify the soil properties input to the model for the corresponding location. Simulations were conducted using observed weather data series for the periods from 1950-1979, and from 1980 – 2009. The two time periods were used to evaluate the effect of possible climate shifts on the hydrologic response at the two locations. The difference in mean annual precipitation at the Waseca location for these two periods was 120 mm, with the latter period being the largest, while for the Marcell location the increase from the 1950-1979 period to the 1980-2009 period was 50 mm.

3.1. Agricultural production landscape: Annual crops vs. perennial grasses

The annual crop considered was continuous corn or corn/soybean rotation, while the perennial vegetation was prairie grass. The soil was represented by the dominant soils in the region, Nicollet clay loam and Clarion loam.

Based on the weather records used, the mean annual precipitation for the period 1950-1979 was observed to be 780 mm, while for the period 1980-2009 it was 900 mm, an increase of 120 mm.

The results of the simulations comparing these two crop types and the effect of changing precipitation are given in Table 3. The ET/I is the evapotranpiration/interception and is the sum of simulated soil evaporation, plant transpiration and interception. Of course the intercepted precipitation ends up evaporating so could just be considered part of ET, but here it is identified as being a distinctive component because of the importance with respect to vegetative cover type. The runoff is the sum of surface runoff and the deep percolation amount. The surface runoff and the deep percolation were added because it is assumed that the deep percolation will eventually part of watershed runoff as the result of either tile drainage or groundwater discharge. The spatial scale at which this will occur is not accounted for in this analysis.

There are dramatic differences in the water balance for the two land cover condition types. The differences in evapotranspiration/interception are largely due to the fact that the perennial grass has a much deeper root zone than the corn, or the corn/soybean condition, 150 cm as opposed to 90 cm, a much higher leaf area index, and also posseses a well-developed organic layer on the soil surface. Based on some published experimetnal data for perennial grasses it is expected that the interception figures given by the simulation might be underestimated. The perennial grass cover condition also produces the significantly smaller amount of total annual runoff in comparison to the corn cover and the corn/soybean cover.

It should be recognized that the simulation model has not been calibrated against field conditions. Data are available for the Waseca site, so it might be prudent to calibrate the model at some future time. However, the results do provide some relative means of comparison to assess the effect of land cover condition on total runoff. Clearly, the perennial cropping condition leads to less total runoff due to the fact that the perennial crop has greater opportunity to capture incident rainfall, by interception due to the greater leaf area index, and by root water uptake due to the deeper rooting system. While the model has not been calibrated, experimental plots at Waseca comparing annual crops to various types of non-woody and woody perennials show (unpublished data) a significant reduction in drain tile flow from the perennial plots.

The increase in precipitation observed in the 1980-2009 period data compared to the 1950-1979 weather data did lead to an increase in total runoff. For the corn cover condition the increase was 60% and for the corn/soybean cover condition the increase was 75%. For the perennial grass cover condition the effect of the precipitation increase was a 65% increase in total runoff. These increases due to precipitation change are compared the land cover effect when changing from annual cover to perennial cover. Changing from perennial cover to corn yields a total runoff increase of about 140% for both periods, while changing from perennial cover to corn/soybean cover yields a total runoff increase of about 100% for the two periods.

There should be no question that an increase in precipitation in a given geographical region will tend to increase runoff amounts because the climate in that region has limited ability to return precipitation to the atmosphere by evaporation (soil evaporation, intercepted precipitation, transpiration). Once this atmospheric capacity for potential evaporation is satisfied, extra precipitation beyond that point will need to become runoff. For the conditions at Waseca it is clear that all of the increased precipitation does not beome runoff because the ET/I values increase with the increase in mean annual precipitation. The increase in the ET/I values are more substantial for the perennial cover, indicating that that type of cover condition has greater capacity to return precipitation back to the atmosphere.

Table 3. Mean annual evapotranspiration/interception, and total runoff (surface and subsurface) for the Waseca, MN location.

Cover type	1950-1979 ET/I (mm)	1980-2009 ET/I (mm)	1950-1979 Runoff (mm)	1980-2009 Runoff (mm)
Corn	475/10	482/13	225	360
Corn/soybean	514/31	524/32	180	315
Perennial grass	592/38	678/42	92	150

The results presented in this subsection are consistent with the analyses conducted in Parts 1 and 2, where it was shown and postulated that landuse and land cover changes have led to increased streamflow at the watershed scale. A useful feature of this subsection is that it provides a mechanistic explantion for the hydrologic changes that have been identified in the first two parts of the report.

3.2. Forested landscape: Deciduous trees vs. evergreen trees

The vegetative cover evaluated for the Marcell location was evergreen trees (spruce) and deciduous trees. The soil was represented by the dominant soils in the region, Menagha loamy sand and Graycalm loamy sand. The rooting depths for the spruce trees was 80 cm, while for the deciduous trees the rooting depths were 100 cm.

Based on the weather records used, the mean annual precipitation for the period 1950-1979 was observed to be 680 mm, while for the period 1980-2009 it was 730 mm, and increase of 50 mm.

The results of the simulations comparing these two crop types and the effect of changing precipitation are given in Table 4. The ET/I quantities and the runoff quantities are described in subsection 3.1.

Unlike the results shown for Waseca, the effect of vegetative type does not show up as being drastically different for the forest land cover condition. The totals of ET and interception are about the same for the evergreen trees and the diciduous trees. The simulation show greater ET for the deciduous trees but less interception than the spruce. The total runoff for the two forest types are nearly the same as well, with only about 5 to 10 mm difference.

The increase in precipitation observed in the 1980-2009 period data compared to the 1950-1979 weather data did lead to an increase in total runoff for the deciduous forest land cover condition, but not for the evergreen forest land cover condition where there was a slight decrease. The differences within a given land cover type were quite small, less than ± 5%.

Unlike the results shown in subsection 3.1 for the agricultural region, in the forested region the increase in precipitation did not lead to a substantial increase in annual runoff. As explained in that subsection, an increase in precipitation will lead to a significant increase in runoff if the system capacity for evaporation has been reached. For the agricultural landscape it was seen that for both of the annual land cover conditions the system was nearly at capacity for evaporation and therefore the increase in annual precipitation led to a nearly equivalent increase in annual runoff. Not so however for the perennial grass condition where a large part of the increased precipitation was absorbed by the evaporative capacity of the perennial land cover. Apparently the forested land cover, both deciduous and evergreen has still substantially more evaporative capacity because the 50 mm increase in precipitation led to a less than 5 mm change in runoff.

Table 4. Mean annual evapotranspiration/interception, and total runoff (surface and subsurface) for the Marcell experimental forest location.

Cover type	1950-1979 ET/I (mm)	1980-2009 ET/I (mm)	1950-1979 Runoff (mm)	1980-2009 Runoff (mm)
Spruce	388/195	418/200	96	93
Deciduous	490/95	516/102	81	85

4. Management implications

The preceding analyses identified hydrologic responses and related water management issues that would not be apparent from the general IPCC predictions. Many of the hydrologic changes we have seen in the Upper Midwest have been caused more by land-use and land cover changes than climate change, at least up to this time. The primary difference from generic climate changes predictions is that some watersheds may respond to rainfall increases via increased groundwater or subsurface tile flow (Zhang and Schilling 2006) more than via increased surface runoff. In these cases, streamflow variability may actually decrease in these watersheds. Increased low and mean flows may have unpredictable ecological consequences when the specific life-history requirements of different organisms are considered.

In light of these results, management issues were identified for different ecoregions. The agricultural, tile-drained landscape of south central Minnesota was compared to the forested region of north central Minnesota using data from the Marcell Forest Experiment Station. Consideration was also given to the steeper Driftless region of Wisconsin, Minnesota and Iowa as well as the North Shore of Lake Superior and the Red River Basin.

In the agricultural, tile-drained landscape of south central Minnesota, increased flow volume may be as important for management as increased flooding particularly for sediment and nutrient total maximum daily loads (TMDLs). Increases have been mostly through sub-surface pipe flow and consequently the large flood magnitude has not increased proportionately as much as the below-flood level flows. While the Minnesota River basin is contained within a deep, wide valley that greatly reduced flooding impacts, the Red River experiences perennial flooding issues.

Another key issue related to hydrologic processes is the fact that much of the flooding in the region is caused by low intensity rains on top of saturated soils and/or combined with snowmelt runoff. It is not caused by the high-intensity rains that occur mainly in the summer which are a major concern associated with climate change in the Upper Midwest. In the Red River basin antecedent soil moisture and the timing of spring rain and snowmelt are the most critical causes of flooding. The drivers of flooding in this region illustrate the importance of understanding the interplay of land-use and land cover change (lost hydrologic storage from wetland storage and decreasing perennial plant coverage), increased tile drainage and climate (increased precipitation) that create water management challenges.

The northern forests responded differently to precipitation increases since 1980. Due to the fact that forests intercept as much as 30-40%% of annual rainfall and transpire much water, forests in north central Minnesota are better buffered against precipitation increases. One major management concern for northern Minnesota is decreased summer baseflow particularly on the streams flowing into Lake Superior. Increased winter flows may lead to reduced baseflow later in the summer creating problems for fisheries and water quality. But in general, the north central forest region (excluding the steep, rocky streams flowing into Lake Superior) is better buffered against future hydrologic changes due to greater ET and interception, but also because of the large water storage volume in lakes and wetlands that still exists in the region. Future fragmentation of the forest through development of vacation homes and sprawl of urban areas could make the region more susceptible to climate changes.

The Driftless region of southeastern MN, western Wisconsin and northeastern Iowa may be the most susceptible to climate changes, particularly in terms of increasing flood flows. The region has steeper topography and much shallower bedrock making it more responsive to intense summer rainstorms. Also the region is closer to the Gulf of Mexico, the source of remnant hurricane storms that dump large volumes of rain in short time periods. This resulted in some of the extreme floods experienced in the region in recent years.

Future research is needed in many areas. One of the major questions identified in this study is when or if a climate change threshold will be reached in the southern agricultural watersheds that have recently experienced large flow increases. Currently the major management issue is too much water, not water scarcity. At what point in the future, will increasing temperatures increase evaporation enough to counter the land-use and land cover changes that have increased flows?

A second major question is how the seasonality of both precipitation and temperature increases will affect the water budget of the Upper Midwest. In recent decades increased temperatures in Minnesota have been via higher winter low temperatures, not higher maximums in the summer. Thus, warmer temperatures have not contributed to greater ET in Minnesota in recent decades. Of course this could change with the more extreme climate change scenarios. Another key consideration is the seasonality of rainfall. If rainfall increases occur in the spring or fall rather than mid-late summer when soil moisture is at a low point, more runoff and flooding will result.

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2) _Publications_: a complete list of all peer-reviewed papers, published abstracts, books, book chapters, reports, and student theses published during the report period as a result of **previous /and/ present projects supported with these funds. Please provide a complete citation with all relevant information, such as author names, title, full journal name or book title, year, inclusive pages, etc. For published abstracts, include title, conference name, location and dates, page numbers or abstract number. For student theses, include title, major, inclusive pages.**

Lenhart, C., J. Nieber, H. Peterson, and M.Titov. Differential Response of Midwestern Watersheds to Climate Change and Implications for Management. Part of a workshop, "The Role of Ecological Restoration in Climate Change Adaptation for the Midwest". Society for Ecological Restoration-Midwest Great Lakes Chapter Annual Meeting Program, Pg. 6. SER-MWGL: Springfield, IL. April 1 to 3, 2011.

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3) _Student Support_: Provide the number of students you have supported or are supporting by these funds (Undergraduate, MS, PhD, Post Docs).

Phd-2 students (Mikhail Titov and Heidi Peterson)

1 Post-Docs (Chris Lenhart) - March 2010 through July 2010; July 2010 to March 2011 as Research Assistant Professor

4) _Presentations:_ list those given by you or your students based on your research, including posters. Include all authors, title, conference name, location, date.

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Lenhart, C.,J. Nieber, H.Peterson, and M.Titov. Differential Response of Midwestern Watersheds to Climate Change and Implications for Management. Part of a workshop, “The Role of Ecological Restoration in Climate Change Adaptation for the Midwest.” Society for Ecological Restoration-Midwest Great Lakes Chapter Annual Meeting, Springfield, IL. April 2, 2011

5) _Awards_: include student awards and faculty awards that were granted during this same time frame.

None.

6) _Related Funding_: please indicate if you have received any related funding that was in some way a result of the WRRI funds. Include title, sponsor, amount, PI and co-PIs, and project period.

The IHA hydrologic analysis done for this grant led directly to hypotheses concerning the ecological impacts of low to mean flow increases that were instrumental in obtaining a DNR grant for Species of Greatest Conservation Need (SGCN).

Title: Assessing the Impacts of Hydrologic and Geomorphic Alteration of Minnesota Rivers on Riverine Turtle Habitat.
Sponsor: Minnesota Department of Natural Resources, Division of Ecological Resources with funding support from the U.S. Fish & Wildlife Service,
Amount: $27,900.
Principal Investigators: John Nieber and Chris Lenhart
Project period: June 2010 to August 30, 2011.

Constraints and opportunities around watershed-wide riparian zone management at the urban-rural interface

Basic Information

Title:	Constraints and opportunities around watershed-wide riparian zone management at the urban-rural interface
Project Number:	2010MN275B
Start Date:	5/1/2010
End Date:	4/30/2012
Funding Source:	104B
Congressional District:	4
Research Category:	Social Sciences
Focus Category:	Management and Planning, Non Point Pollution, Law, Institutions, and Policy
Descriptors:	None
Principal Investigators:	Mae A. Davenport

Publications

1. Davenport, M.A. 2011. Community Capacity Rapid Assessment: Getting to Know your Community. Community Assessment Workshop, Minnesota Pollution Control Agency, St. Paul, MN, March 29, 2011.
2. Davenport, M.A. 2011. Building Capacity for Watershed Management in Local Communities. 2011 Water and Watersheds Conference, Minnesota Pollution Control Agency, St. Paul, MN, February 9, 2011.
3. Davenport, M.A. 2010. Understanding Adaptive Capacity for Sustainable Watershed Management. Water Resources Science Seminar. St. Paul, MN, December 3, 2010.
4. Davenport, M.A. 2010. The Human Dimensions of Watershed Science and Management. Metropolitan Association of Soil and Water Conservation Districts. Arden Hills, MN, November 18, 2010.
5. Davenport, M.A. 2010. Drivers and Constraints Affecting Community Capacity for Watershed Management. Cache River Symposium. Vienna, Illinois, October 12, 2010.

Constraints and opportunities around watershed-wide management at the urban-rural interface

Principal Investigators

Mae A. Davenport, Assistant Professor, Department of Forest Resources

Funding Source: USGS-WRRI 104B/CAIWQ Grants Program

Project Duration: 3/1/10-2/28/11
Reporting Period: 3/1/10-2/28/11

RESEARCH PROJECT SYNOPSIS: PRELIMINARY RESEARCH FINDINGS

PROJECT PURPOSE

It has become increasingly evident that healthy ecosystems and healthy human communities are interdependent and mutually supporting. At the same time, the conversion of natural lands to urbanized uses has continued—at an estimated 1.6 million acres each year (USDA Natural Resource Conservation Service, 2009). Land-use decisions at the local level are critical to environmental planning and management, especially at urban-rural interfaces where dramatic land use changes can occur rapidly. Many resource professionals and community decision makers across the U.S. are beginning to identify and pursue common goals in sustainable watershed management (SWM). Through the collaborative planning and collective action of local governments, non-government organizations, and dedicated citizens, many communities across the nation are restricting land uses, adopting sustainable development practices, protecting critical habitats, and restoring altered ecosystems (Portney, 2003) to ensure watershed health and in turn, the provision of ecosystem services that will sustain their communities into the future. Still, other communities continue to engage in land uses and development practices that compromise watershed health and in turn, the health and vitality of their communities. For example, while conservation practices such as riparian buffer management are promoted by federal, state and in some cases local government agencies, many landowners have not adopted these practices (Valdivia and Poulous, 2009). Unfortunately, the landowners' underlying beliefs and attitudes that drive or constrain conservation behaviors have not been extensively studied. The overarching goals of the project are to identify opportunities for and constraints to SWM at the local level and to establish critical capacities communities need to engage in SWM. Three questions underpin the project: (1) What drives communities and individuals to adopt SWM strategies? (2) What are constraints to SWM? (3) How can resource professionals, community decision makers and other stakeholders build community capacity to protect watershed health? The research project presented here is based on a qualitative and quantitative investigation of these questions.

RESEARCH DESIGN

In-Depth Interviews with Watershed Stakeholders

Data were gathered through in-depth interviews with three expert audiences: (1) community decision makers (e.g., managers, planners and elected officials), (2) water resource managers and professionals in the area (e.g., Minnesota Pollution Control Agency, Soil and Water Conservation Districts, Watershed Management Organizations) and (3) active community members (e.g., non-profit group representatives). The interviews engaged participants in one-on-one dialogue about community capacity for sustainable watershed management. A semi-structured interview format fostered candid, individual reflection, as well as focused discussion around community-level projects, programs, and partnerships. Interviews were initiated in the fall of 2010. To date, 32 interviews have been conducted with 34 individuals who have a vested interest in management of the Vermillion River and Sand Creek watersheds in the Twin Cities Metropolitan Area. Participation in the interviews was voluntary and all efforts were taken to maintain participants' confidentiality. Three individuals invited to participate in the study refused. The interview guide was pre-tested and data collection protocol was approved by the University's Institutional Review Board. Interviews were audio-recorded with participants' informed consent. Interview data were analyzed for underlying themes relevant to the guiding research questions. Researchers used standard qualitative analysis methods adapted from Corbin and Strauss (2008), Krueger and Casey (2000), and Charmaz (2006) to code and organize the data, identify predominant themes, and explore relationships and patterns among themes. Researchers took copious and detailed field notes following interviews to record the interview context not captured by an audio-recorder.

Survey of Riparian Landowners

Data were collected through a self-administered survey of a random sample of riparian landowners whose property is located within Scott County and the Sand Creek watershed. The survey was administered in March 2011. A database of riparian landowners living within 300 feet of a stream in the Sand Creek watershed and in Scott County was obtained from Scott County Watershed Management Organization. This database was based on publicly available property tax records and included landowner names, addresses and subwatershed identification. A proportionate sample of landowners (approximately 63%) in each subwatershed was randomly selected. An adapted Dillman's (2009) Tailored Design Method was used to manage the survey distribution and increase response rates. The survey was administered in four waves: two mailings of the survey instrument with a cover letter and two reminders, one of which included a watershed map. While standard protocol recommends a pre-notification letter as the first contact with the sample pool, in this study reminder postcards were delivered ahead of schedule prior to the pre-notification postcard and survey instrument itself. Thus, we adapted the standard Tailored Design Method to achieve an appropriate response rate. The survey instrument was designed based on literature review, and feedback from a pre-test and a pilot test of the instrument. The questionnaire included a variety of fixed-choice and scale questions. Several questions were adapted from survey instruments used in previous studies of attitudes, beliefs and values of conservation behaviors (Stern et al., 1993; Schultz, 2001; Schwartz, 1977; Harland et al., 2007; Matsumoto et al., 1997). A total of 1000 surveys were distributed by U.S. mail. Of the 1000 questionnaires mailed, 43 have been returned undeliverable. To date, 422 completed questionnaires have been received for a response rate of 44%. Basic descriptive statistics were conducted using Statistical Package for Social Sciences (SPSS release 17.0).

PRELIMINARY RESEARCH FINDINGS

In-Depth Interviews with Watershed Stakeholders

Interview findings presented here are based on 25 completed and analyzed interviews with 27 watershed stakeholders. In two instances, two people were interviewed together. The findings presented in this section respond to the following questions:

1. Who are interview participants?
2. How do participants define sustainable watershed management?
3. Who do participants believe should be responsible for sustainable watershed management?
4. What opportunities exist for promoting sustainable watershed management?
5. What constrains sustainable watershed management?

1. Who are interview participants?

Interview participants represent diverse sociodemographic and behavioral characteristics with varying roles in watershed management (Table 1).

Table 1. Study participant profile

Sociodemographic/behavioral characteristic		n
Gender	Male	20
	Female	7
Race	White/Caucasian	27
Ethnicity (Hispanic)	Yes	1
	No	25
	No response	1
Age	Mean	46
	Minimum	27
	Maximum	70
Watershed of focus	Sand Creek	11
	Vermillion River	15
	Both	1
Own land in watershed	Yes	14
	Maybe	1
	No	11
	No response	1
Occupation/Role*	Appointee -County	1
	Appointee -Regional	1
	Business owner	1
	Elected -County	2
	Elected -Non-Profit	2
	Elected -Regional	2
	Elected -Township	2
	Professional	5
	Staff -City	3
	Staff -County	5
	Staff -Federal	1
	Staff - Regional	6
	Staff -State	3
	Retired	1

*Participants may hold more than one role

2. How do participants define sustainable watershed management?

When asked how they define sustainable watershed management participants tended to explain the concept in terms of processes or outcomes (Table 2). Many participants described sustainability as a balance of land uses and meeting social, economic and ecological needs. For some, sustainability meant simply “doing no harm;” for others, sustainability requires better protection resulting in high quality aquatic ecosystems. Several participants described a process of getting people engaged, defining a vision and taking action. For example, a regional water resource decision-maker emphasized the need for an “active citizenry:”

> You need an active group of people, you need a long term plan and you need various financial resources to accomplish [that]. As long as you have an active citizenry that really cares about the resources and is willing to put dollars into various programs. Having a plan, what is our long-term goal…to protect the water, take care of

impairments and then setting priorities. …A good sustainable plan needs those types of things.

Table 2. Definitions of sustainable watershed management

Major themes	Subthemes	Sub-subthemes
Process	*Engaging People in the Issue*	• Through education (for an educated citizenry) • Consensus of a system for management • More involvement from stakeholders & landowners
	Creating a Common Definition	• Identify goals • Identify ways to deal with conflicts • More input from stakeholders & landowners
	Planning & Decision Making	• Identifies priorities (areas, projects, etc.) • Has a budget • Contains realistic & flexible (goals, projects, etc.) • Has a strategy(ies)
	Setting Standards & Policies	
	Implementation	• Of projects and programs • Of policies
	Assessment	• Monitoring streams
Outcomes	*A Condition*	• Biotic diversity • Maintained and/or improved • Free of impairments • Trout streams • High quality resources • Healthy aquatic communities • Sufficient quantity of resources • Doing no harm • Water is protected
	Uses	• Meet recreation needs • Meet economic needs • Balance of land uses • Future generations

3. Who do participants believe should be responsible for sustainable watershed management?
When asked who should be responsible for SWM, many respondents identified multiple responsible parties (Table 3). A water resource professional explained the need to have one organization take the lead role in SWM. He surmised that combining the strengths of the local watershed organization and soil and water conservation district would be most effective:

> We've kicked around the idea …that what would almost seem to be an ideal combination would be something similar to Nebraska where you have some organizations that's effectively a Soil and Water Conservation District [SWCD] and a watershed district rolled into one entity. So you get both of the good things there where, you know, a watershed organization [tends] to be good at kind of the big policy, the planning, that type of thing. But, then when it comes to actually getting stuff done on the ground then the SWCD folks are kind of the better arm and agent to do that.

Table 3. Responsibility for SWM

Major Theme	Subthemes
Many entities	• Everyone • Local government organizations
One entity	• A watershed organization • The county • A new entity
Individuals	
Everyone	

4. What opportunities exist for promoting sustainable watershed management?
Participants were asked several questions relating to opportunities to promote water resource and watershed management. Responses were wide-ranging and in most cases, quite descriptive. Two categories of capacities emerged: foundational resources (Table 4) and mobilizing assets (Table 5). For example, a watershed organization commission member described citizen awareness through education and engagement as fundamental to building capacity for SWM. The participant said,

> Again, I think it's education. I think it's educating the public and getting people engaged. Getting people engaged as volunteers, getting people engaged in the process, getting people engaged in starting to utilize the land more. Things like, if you put in an observation platform, if you put in a walking trail, if you put in a bike trail, if you do something that gets people off of their couches and into the environment, then they start to value what they have, right? So I think you have to engage the citizens in order for them to really value it.

Table 4. Critical community capacities: Foundational resources

Major theme	Subthemes
Ecological opportunities	• Open space • Water bodies • Presence of iconic species • Ecological integrity • An ecological crisis moment
Financial support	• Long-term funding sources • External sources of funding • Sufficient funds for staff and programs • The ability to impose taxes or fees
Human resources	• Willing landowners • Volunteers • Decision makers • Staff at all levels of local government • Staff from state agencies • External partners
Effective plans	• Respected • Strong • Comprehensive • Nested • Flexible • Specific • Subject to review • Local

Table 5. Critical community capacities: Mobilizing assets

Major theme	Subthemes
Decision maker awareness	• About the human communities they serve • About the landscape and water bodies • How people relate to the water • How to use policy and management tools effectively • The area's development plans • How terms are defined • How to communicate effectively • When they are lacking resources
Landowners/property owner awareness	• Why the watershed is important • What the problems are • How their actions impact the watershed • How watershed health impacts them • How the planning process works
Support from community groups	• The citizenry • NGOs • Local community leaders • Local businesses • State level decision makers
Relationships between individuals and groups	• Local citizens/landowners, community groups, governments and resource agencies • Cooperation • Trust
Institutional arrangements	• Involves formal citizen committees • Has overlapping programs • Allows for cross jurisdictional collaboration • Forms a WMO • Fosters reviews and information sharing • Involves boards and associations at multiple scales • Involves experts • Has leadership • Is a manageable size • Is in a metro location • Combines the best of SWCDs and watershed districts
Conservation tools/strategies	• Rules, regulations and policies • Education • Programs and projects • Local media • Incentives/disincentives • Enforcement • Civic engagement • Common goals

5. What constrains sustainable watershed management?
When asked about constraints and challenges associated with water resources and watershed management, several major themes emerged (Table 6). Participants provided insight into how resources, relationships, and governance can lead to conflict and competition rather than collaboration and cooperation. For example, a county resource manager described the complexities inherent in watershed management. The participant noted that values and roles are “fragmented”:

> Coordination, prioritization, confusion among the landowners, inefficiencies, no collective vision for how each of their roles fit within the larger whole. It’s so fragmented. That’s not just [this watershed], that’s water governance throughout the state. You have all these different layers with little pieces. it’s very confusing and not very efficient.

Table 6. Constraints to sustainable watershed management.

Major theme	Subthemes
Degraded natural resources	• Land is altered and developed • Not enough land for conservation • Water resources are strained and impaired (erosion, run-off, flooding, TMDLs) • High demand on insufficient rural infrastructure • Resources threatened by future development • Resources under pressure from high density housing
Funding limitations	• Competing priorities for limited funds • Funding less available outside of Twin Cities Metropolitan Area • Funding mechanisms such as taxes and fees insufficient for resource needs • Funding mechanisms such as taxes and fees unpopular • Lack of long-term funding mechanisms available for programs and projects • High cost of conservation and restoration programs
Limited or competing knowledge and awareness	• Citizens and decision makers lack awareness of water resources conditions • Citizens and decision makers lack knowledge and understanding of conservation practices • Few education programs about water resources and conservation practices • Citizens lack awareness of personal impact • Citizens lack understanding of governmental roles • Science-based knowledge limited
Trust	• Citizen distrust of government • Distrust of information sources • Landowners lack trust in county • Townships lack trust in county

Major theme (cont'd)	Subthemes
Local planning	• LGUs lack coordination/cooperation with other entities • Limited county communication with local government units (LGUs) • Lack of conservation planning by LGUs • Planning is short-term • No common definition of sustainable watershed management • Lack of civic engagement (communication, collaboration, and cooperation) • Values conflict between landowners and government • LGUs lack resources to plan effectively
Unclear jurisdiction and authority	• Political and watershed boundaries are not aligned • Conflict about overlapping/competing land use authority (e.g., local or regional scale) • Uncertainty over who has land use authority
Competing land uses	• Conflicts between rural and urban land uses • Development pressure threatens with rural character • Development strains water/natural resources • Lack of conservation practices by landowners and LGUs • Lack of conservation practices by developers
Civic engagement	• Public priority is not water resources • Attitude of apathy among citizens • Public meetings not well attended • Citizens/landowners not engaged in planning and decision making • Citizens don't know what is going on • Community groups not engaged in planning and decision making • Programs fail to motivate landowners to participate
Land use and conservation policies/regulations	• Policies are ineffective • Policies are lacking • Polices are expensive • Policies are inflexible • Policies are weak • Policies appear unjustified • Regulation inefficient and unpopular • Regulations are inconsistently implemented • Gaps in regulation of agriculture

Major theme	Subthemes
LGU resource limitations	• Inadequate and ineffective programs • Insufficient staffing to run programs and projects • Insufficient staffing to identify and apply for grants • Insufficient staffing to coordinate partnerships • Staff lacks expertise • Staff turnover and personalities affect relationships with citizens • Office space lacking
Political conflict/redundancy	• Inefficiencies, including bureaucracy and redundancy of government regulations • Solutions not politically feasible • Elected officials with political agendas • Unequal power among local government units • Influence of special interests on government (e.g., agriculture) • Competition for limited financial resources • Conflict between land use priorities (recreation, preservation, development) • Lack of governor support

Riparian Landowner Survey

These preliminary results of the riparian landowner survey are based on the initial 301 questionnaires received and analyzed. The findings presented in this section respond to the following questions:

1. Who are respondents?
2. What are respondents' beliefs and concerns about the environment, water quality and streamside buffers?
3. Who influences respondents' decisions about conservation practices?
4. What would motivate respondents to adopt or maintain streamside buffers?
5. What are respondents' perspectives on management actions to protect water resources?

1. Who are respondents?

A majority of the respondents (79%) were male and between 46 and 75 years of age (70%). More than two-thirds of respondents had attended at least some college. A vast majority of respondents reported their race as white (97%). The annual household income of 70% of the respondents was $50,000 or more. About one-third of the respondents reported that they depend on their land for income. Approximately 63% of the respondents reported that the land they own is more than 6 acres (Table 6). A majority (78%) of the respondents owned and managed their land and most respondents (88%) make their own decisions about land management. Almost 40% of respondents use their land for agricultural production. Almost 40% report that they maintain buffers on all streams and ditches on their property, while 25% of respondents reported that they do not have streams or ditches on their property (Table 7).

Table 7. Respondents' use of streamside buffers on their land/property

Response	Count	Percent
I do not have streams/ditches on or adjacent to my property	71	25.4
I maintain buffers on <u>all</u> streams/ditches on or adjacent to my property	105	37.5
I maintain buffers on <u>some</u> streams/ditches on or adjacent to my property	52	18.6
I do not maintain buffers on any streams/ditches on or adjacent to my property	52	18.6
Total	280	100.0

Source: Question 11
Survey question: To what extent do you maintain streamside buffers on your land/property?

2. What are landowners' beliefs and concerns about the environment, water quality, and riparian buffers?

On average respondents somewhat to strongly agree that they are concerned about water quality for future generations, wildlife, aquatic life, and their own health (Table 8). When asked about their agreement with several belief statements, the majority of respondents agreed that streamside buffers (SB) help to improve water quality for downstream communities (81%) and that SBs should be protected for their wildlife habitat (72%, Table 9). A majority of people disagreed that protecting the environment will threaten jobs for people like them (60%) and that SBs reduce the value of land (51%).

Table 8. Respondents' concerns about water pollution

I am concerned about the consequences of water pollution for…	**N**	**Mean[a]**	**SD**	**Strongly disagree**	**Somewhat disagree**	**Neither agree nor disagree**	**Somewhat agree**	**Strongly agree**	**Don't Know/Not Sure**
Future generations	297	1.45	0.753	1.3	1.0	4.7	36.5	55.9	0.7
Wildlife	295	1.35	0.843	2.0	1.3	7.7	36.9	51.0	1.0
Aquatic life	294	1.35	0.777	1.0	1.3	8.4	39.3	48.7	1.3
My health	297	1.12	0.979	3.7	2.3	13.0	39.5	40.8	0.7
People in my community	292	1.11	0.924	2.7	2.0	14.8	41.1	37.7	1.7
My lifestyle	293	0.70	0.981	3.3	5.4	29.8	38.1	21.4	2.0

Source: Question 5
[a]Responses based on a five-point scale from strongly disagree (-2) to strongly agree (+2).
Survey question: To what extent do you agree or disagree with the following statements?

Table 9. Respondents' beliefs about the environment, water quality, and riparian buffers.

	N	Mean[a]	SD	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Don't Know/Not Sure
Streamside buffers help to improve water quality for people living downstream.	276	1.31	0.864	2.0	1.4	8.5	35.3	46.4	6.4
Streamside buffers should be protected because they provide habitat for wildlife.	271	1.12	0.939	2.0	2.7	15.3	34.4	37.8	7.8
The balance of nature is delicate and easily upset.	291	0.89	1.062	3.0	9.1	15.9	38.2	32.1	1.7
The effects of water pollution on public health are worse than we realize.	278	0.72	1.109	4.1	10.2	20.1	34.4	25.9	5.4
Water pollution poses serious threats to the quality of life in my community.	282	0.40	1.211	7.7	14.5	24.6	27.9	20.2	5.1
Claims that current levels of pollution are changing the earth's climate are exaggerated.	283	0.10	1.460	19.6	17.9	12.2	25.3	20.6	4.4
Laws to protect the environment limit my choices and personal freedom.	292	-0.22	1.276	20.2	23.6	20.9	24.9	8.8	1.7
Streamside buffers reduce the value of land.	266	-0.69	1.100	26.9	24.5	25.9	10.9	2.4	9.5
Protecting the environment will threaten jobs for people like me.	281	-0.93	1.119	40.5	19.9	24.3	7.4	2.7	5.1

Source: Question 4

[a]Responses based on a five-point scale from strongly disagree (-2) to strongly agree (+2).

Survey question: To what extent do you agree or disagree with the following statements?

3. Who influences landowners' decisions about conservation practices?

Respondents were asked to indicate how likely or unlikely it is that their decisions about conservation practices would be influenced by key individuals and groups (Table 10). On average, family and their county's soil and water conservation district were most influential in respondents' decisions about conservation practices. Overall, respondents were least likely to be influenced by their county farm bureau or property rights organizations.

Table 10. Individuals or groups that influence landowners' decisions about conservation practices

	N	Mean[a]	SD	Very unlikely	Somewhat unlikely	Neither likely nor unlikely	Somewhat likely	Very likely	Don't Know/Not Sure
My family	288	1.01	0.95	3.4	1.7	18.0	42.4	32.2	2.4
My county's Soil and Water Conservation District	283	0.90	1.02	5.1	3.4	14.5	45.6	27.0	4.4
MN DNR	285	0.81	1.13	7.4	4.4	14.9	42.2	27.4	3.7
My local Water Management Organization	275	0.72	1.03	5.7	3.7	20.3	44.6	18.6	7.1
MPCA	278	0.61	1.20	9.8	5.4	17.6	39.9	21.3	6.1
My neighbors	289	0.55	0.96	5.7	6.4	23.0	53.0	9.5	2.4
My local government	281	0.52	1.06	7.1	7.1	23.5	44.6	13.3	4.4
People in my community.	284	0.51	0.88	3.7	8.1	25.1	53.6	5.8	3.7
Environmental organizations	287	0.35	1.22	11.1	12.1	20.2	38.0	15.2	3.4
Sportspersons club	286	0.31	1.20	10.5	12.9	24.7	33.9	14.9	3.1
My county's Farm Bureau	266	0.12	1.11	10.8	10.5	33.1	28.0	7.4	10.1
Property rights organizations	281	0.00	1.13	12.5	15.8	32.0	27.6	6.7	5.4

Source: Question 8

[a]Responses based on a five-point scale from very unlikely (-2) to very likely (+2).

Survey question: How likely or unlikely is it that the following individuals or groups would influence your decisions about conservation practices on your land/property?

4. What would motivate landowners to adopt or maintain streamside buffers?

Respondents were asked about their agreement with statements related to constraints and opportunities for adopting or maintaining SBs (Table 11). A majority of respondents agreed that they would be more likely to maintain or continue to maintain SBs, if they had access to financial resources (65%) and if they could learn how to maintain SBs for water quality (65%).

Table 11. Respondents' views about streamside buffers

I would be more likely to maintain or continue to maintain streamside buffers on or adjacent to my property if...	**N**	**Mean[a]**	**SD**	**Strongly disagree**	**Somewhat disagree**	**Neither agree nor disagree**	**Somewhat agree**	**Strongly agree**	**Don't Know/Not Sure**
I had access to financial resources to help me plant and maintain streamside buffers.	221	0.82	1.07	4.7	5.6	18.9	38.6	27.0	5.2
I could learn how to maintain streamside buffers for water quality.	223	0.82	1.02	4.7	2.6	23.7	39.2	25.9	3.9
I could learn how to maintain streamside buffers for soil conservation.	222	0.73	1.00	4.7	3.0	26.7	39.7	21.6	4.3
I knew more about how to plant and maintain streamside buffers.	223	0.63	1.00	4.3	3.8	34.6	32.5	20.1	4.7
I could learn how to maintain streamside buffers for wildlife benefits.	221	0.60	1.06	5.6	5.2	31.0	33.2	20.3	4.7
I could learn how to maintain streamside buffers for scenic quality.	217	0.52	1.11	6.9	6.4	29.6	32.2	18.0	6.9
I knew more about the benefits of streamside buffers.	221	0.52	1.00	4.7	6.0	34.6	33.8	15.4	5.6
I had help with the physical labor of planting and maintaining streamside buffers.	220	0.39	1.09	6.9	9.9	31.8	31.8	14.2	5.6
I could attend a community workshop or field day on streamside buffers.	219	0.24	1.12	11.2	6.4	35.6	30.5	10.3	6.0
I was compensated for lost crop production because of streamside buffers.	216	0.24	1.16	10.3	7.3	39.9	20.2	15.0	7.3
My neighbors maintained streamside buffers.	212	0.19	1.16	11.2	7.7	36.9	22.7	12.4	9.0
I could be enrolled in a registry program that recognizes local conservation stewards.	215	-0.15	1.07	13.7	12.9	45.1	14.6	6.0	7.7

Source: Question 12

[a]Responses based on a five-point scale from strongly disagree (-2) to strongly agree (+2).

Survey question: To what extent do you agree or disagree with the following statements?

5. What are landowners' perspectives on management actions to protect water resources?

Landowners were asked to indicate how likely or unlikely certain management actions are to protect water resource quality in Minnesota (Table 12). According to respondents, expanding incentive-based programs has the highest likelihood of protecting water resource quality in Minnesota. In contrast, increasing water resource regulations was deemed to be the least likely to protect water resource quality. Still, 50% or more of respondents believed that six of the seven actions would be at least somewhat likely to protect water resource quality in Minnesota.

Table 12. Respondents' perceptions about management actions to protect water resources.

	N	Mean[a]	SD	Very unlikely	Somewhat unlikely	Neither likely nor unlikely	Somewhat likely	Very likely	Don't Know/Not Sure
Expanding incentive-based programs that offer payments to landowners for conservation practices.	277	0.96	1.08	4.2	6.9	11.8	38.4	34.6	4.2
Promoting voluntary adoption of conservation practices through increased education and outreach programs.	274	0.79	0.97	2.4	7.3	20.4	42.6	22.1	5.2
Coordinating land use and water planning efforts across communities.	270	0.79	0.97	3.1	5.2	22.0	41.8	22.0	5.9
Engaging more citizens in local land use and water resource decision making.	266	0.76	0.98	2.4	6.6	23.3	38.7	21.6	7.3
Conducting more water quality research and monitoring.	273	0.74	1.04	4.5	7.9	15.2	46.2	20.3	5.9
Enforcing existing land use laws and regulations.	272	0.73	1.07	4.9	7.3	19.1	40.3	22.9	5.6
Increasing regulations that specifically address water resource management.	265	0.32	1.22	9.8	12.9	23.1	31.1	15.7	7.3

Source: Question 14

[a]Responses based on a five-point scale from very unlikely (-2) to very likely (+2).

Survey question: In your opinion, how likely is it that the following management actions will protect the quality of water resources in Minnesota?

LESSONS LEARNED THUS FAR

This project was designed to help water resource managers and professionals, community decision-makers and other stakeholders better understand constraints to and opportunities for sustainable watershed management (SWM). The in-depth interviews offer valuable insights into the perspectives of diverse stakeholders about SWM and its drivers and constraints in the urban-rural interface. Survey findings provide a snapshot of riparian landowner beliefs and attitudes associated with conservation practices in general, and specifically the management of riparian buffers. Lessons learned to date are described below.

1. Watershed stakeholders interviewed altogether articulated a multi-dimensional definition of SWM with process and outcome attributes. While stakeholders had different perspectives on who should be responsible for SWM, the predominating belief was that collaboration of multiple groups is required. Process-focused definitions included identifying goals, involving stakeholders, and implementing and assessing programs and policies. Outcomes-focused definitions included maintaining and improving the watershed and meeting economic and recreational needs. This multi-dimensional definition should be

considered by water resource professionals in planning and management. While not every stakeholder appears to agree on specific details, the study uncovered several shared elements that can inform future programming.

2. Community capacity for SWM requires diverse foundational resources and mobilizing assets. The realization of SWM can be constrained by many factors associated with resource conditions or limits, knowledge gaps, distrust and uncertainty, policy and regulation implementation problems, and political conflict and redundancies. Understanding what opportunities and constraints influence SWM is important to state policy-makers, water resource managers and professionals, local decision makers, and citizens. While current water resource programs tend to focus on foundational resources, mobilizing assets including relationship and trust building are critical to strengthening and sustaining capacity.

3. Riparian landowners surveyed vary in their beliefs and attitudes towards the environment and watershed management. The vast majority of respondents agreed that streamside buffers (SB) improve water quality for people downstream and that SB protection is important for protecting wildlife habitat. Overall, respondents generally disagreed that environmental laws limit personal freedoms, that streamside buffers reduce the value of land, and that protecting the environment threatens jobs for people like themselves. The findings also indicate that respondents were concerned about the consequences of water pollution for future generations, wildlife and aquatic life. Water resource professionals should be encouraged that respondents expressed concern about the consequences of water pollution. With respect to SB programming, it appears the importance of SBs to downstream communities and to wildlife should be emphasized.

4. Riparian landowners' conservation practices are most influenced by family, the county Soil and Water Conservation Service, and the MN Department of Natural Resources. Still, more than half of respondents reported that they would be at least somewhat likely to be influenced by 9 of the 12 groups listed. On average, respondents would be most likely to maintain or adopt SBs if they had access to financial resources or if they could learn how to maintain buffers for water quality. This finding suggests that education programs focusing on SBs management for water quality may be just as effective as financial incentive-based programs. Respondents were largely neutral or unsure about whether enrollment in a registry program that recognizes local conservation stewards would encourage their adoption or maintenance of SBs.

5. Watershed management actions promoting incentive-based and education programs were deemed most likely to protect water quality in Minnesota, while enforcing existing or increasing regulations were perceived as least likely to have this outcome. It is important to note, however, that for six of the seven watershed management actions provided, more than half of respondents expressed the belief that the actions would be at least somewhat likely to protect water quality in Minnesota. These findings suggest that landowners view a variety of management actions as contributing to water quality in the state.

ACKNOWLEDGEMENTS
The project described in this report was supported by Grant/Cooperative Agreement Number 06HQGR0093 from the United States Geological Survey (USGS). Its contents are solely the responsibility of the authors and do not necessarily represent the views of the USGS. Additional funding was provided by the Office of the Vice President of Research, University of Minnesota. The authors would like to acknowledge Amanda Sames, Paula Guetter, and Christine Yaeger for their assistance with data collection and analysis. Gratitude is extended to Paul Nelson, Scott County, and Mark Zabel, Dakota County, for their insight on survey design and participant recruitment.

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USGS Award No. G10AP00050 Data Management and GIS Analysis for the Ecosystem Technical Work Group

Basic Information

Title:	USGS Award No. G10AP00050 Data Management and GIS Analysis for the Ecosystem Technical Work Group
Project Number:	2010MN276S
Start Date:	2/1/2010
End Date:	9/30/2011
Funding Source:	Supplemental
Congressional District:	
Research Category:	Biological Sciences
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	

Publications

There are no publications.

Progress report for award G10AP0050, "Data Management and GIS support for the Ecosystem Technical Working group."

Author: Terry Brown
Date: May 7, 2010
Email: tbrown@nrri.umn.edu

Reporting period March 1, 2009 through February 28, 2010.

As the budget for this project became active February 17, 2010, some of the activity discussed occured after the end of the reporting period.

This progress report follows the structure described on page three (section C.1.b) of the Assistance Award.

1. A comparison of actual accomplishments to the goals established for the period and any significant research findings.

   In accordance with the goals listed on page two of the Assistance Award:

   - Maps of regional and local areas of apparent vulnerability to water level change were produced.
   - Collection and description (metadata generation) of data sets is ongoing as the study site list is finalized.
   - Pending final site selection an updated Lake Superior wide bathymetry layer was built from from a newly digitized set of soundings not previously incorporated in bathymetry data sets. Assessment of the shoreline resolution of this data set continues.
   - The spatial framework and parameterization necessary for the construction of the Performance Indicators was discussed and refined in large and small group meetings.
   - Guidance for field collection of bathymetry data was provided.

2. Reasons why established goals were not met, if applicable.

   N/A

3. Other pertinent information including, where appropriate, analysis and explanation of cost overruns or projected changes in the time or funding needed for completion of the project objectives.

   N/A

4. One copy of any publication resulting from the USGS-supported project.

   N/A

USGS Award No. G11AP20000 Identifying and Evaluating Best Practices for the Adaptive Management of Water Resources

Basic Information

Title:	USGS Award No. G11AP20000 Identifying and Evaluating Best Practices for the Adaptive Management of Water Resources
Project Number:	2011MN306S
Start Date:	11/23/2010
End Date:	11/22/2011
Funding Source:	Supplemental
Congressional District:	
Research Category:	Social Sciences
Focus Category:	Management and Planning, Law, Institutions, and Policy, None
Descriptors:	
Principal Investigators:	Deborah L. Swackhamer

Publications

There are no publications.

Identifying and Evaluating Best Practices of Adaptive Management for Water Resources

Principle Investigators:
Deborah L. Swackhamer, University of Minnesota
William J. Focht, Oklahoma State University
Jeffrey S. Allen, Clemson University
Brian E. Haggard, University of Arkansas

Project Duration: 11/23/10-11/22/11
Reporting Period: 3/1/10-2/28/11

I. Statement of Results or Benefits

We are conducting a policy-level examination of adaptive management strategies that have been used by federal agencies as related to water resources management, with particular attention to the use by the US Army Corp of Engineers (USACE). We will review adaptive management policies, barriers, and opportunities for USACE, with the intent of having this analysis be useful for other agencies. Ultimately this research will identify alternatives for best practices for conducting national water management policy.

This research will promote collaboration and interaction with university researchers and USACE researchers, as well as strengthen relationships between WRRI/NIWR and IWR.

This work will also have the added benefit of training two graduate students, one at the University of Minnesota and one at Clemson University. Engaging students in this project is vital to future human resource needs in federal and state agencies, as it prepares new water resource leaders, managers, and researchers to replace a work force that is being depleted by retirements. It also provides students the opportunity to engage in applied research with federal and state water professionals.

The results of this work will benefit other federal and/or state agencies engaged in water resources management and policy, by providing an analysis of alternatives for adaptive management that may be applied to their specific situations and needs.

II. Nature, Scope, and Objectives, with Timeline

We are responding to the following research priority:

> *"Develop definitions, descriptions, methodologies, and an identification of challenges within the Federal sector and federal-state partnerships for conducting adaptive management within the field of water resources."*

We are reviewing adaptive management practices at facilities based on literature reviews, telephone/email conversations with appropriate facility personnel, and eventually, one or two on-site meetings at facilities or with agency personnel who have exceptional best practices in place. Recommendations will also address boundaries for the use of adaptive management, i.e. what is not feasible and why.

Our **objectives** are as follows: (1) Identify and define the approaches that have been used for adaptive management of water resources ; (2) describe the specific adaptive management practices that have been used by the USACE and evaluate their rigor and effectiveness; (3) describe some selected adaptive management practices used by other federal and state agencies that have been successful, as well as selected examples of those that have not; (4) assess these cases for opportunities, barriers, lessons learned; and (5) make recommendations for best practices of adaptive management for the USACE and other federal agencies that engage in water management and policy.

Our timeline is as follows:

- Work began November, 2010 (date of award receipt).
- Literature review and identification of existing practices by July, 2011.
- Interviews and visits by September, 2011
- Assessment and evaluation of data collected by November, 2011
- Final draft paper end of November, 2011.

These investigations are being conducted pursuant to provisions contained in the “Water Research” section of the Water Resources Research Act of 1984, (Public Law 98-242) and subsequent federal legislation, which amends or supersedes this Act.

III. Review of Literature

Williams, Szaro and Shapiro (2007) define adaptive management within the federal context as “a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood.” Though adaptive management exists within this U.S. Department of Interior framework and throughout the federal bureaucracy in various forms, it has not been formalized in most contexts. Bowsher (1992) and May, Workman and Jones (2008) point out that government agencies today often have little established policy direction, and bureaucratic limitations usually halt change before it can get going. The tactic of centralization and not being limited to formal procedures (a beginning point for adaptive management) helps speed action and is much more flexible in decision making, but is also less stable and more disruptive due to diffused accountability. Agencies tend to be centralized at the top, but have authority delegated to the bottom, leading to two different systems of management organization that have trouble communicating with each other. The authors provide the example of The Department of Homeland Security (DHS) with most of its authority centralized and focused too much on terrorism, leading to major problems in the other areas that it was in charge of (even though our country’s level of disaster preparedness is more stable than our level of terrorism preparedness). Wise (2006) provides insight into the potential of using adaptive management within DHS for situations like the hurricane Katrina disaster. Wise noted that it was not explicitly specified who really was in charge of the total relief effort, therefore it was also unclear who to blame for the organizational problems and the lack of integrated planning capabilities hurts the government’s effort to coordinate multiple agencies and groups in a relief effort.

No model is suitable for all situations, but whatever is put into place needs to account for the nature of the tasks to be performed and the nature of the environment in which these tasks are performed. Menzel (2006) and Scavo, Kearney and Kilroy (2007) echo the frustration in the FEMA response to Katrina indicating that most problems involved either decision makers on the ground level during the effort being uninformed of decisions made in the bureaucracy or in high ranking federal officials being blind to the exact kinds of efforts being made on the ground. Waugh and Streib (2006) and Kapucu, Augustin and Garayev (2009) go so far as to say there is already too much hierarchical bureaucracy in the federal system and they wonder if we should even have agencies such as FEMA, but that ideally there should exist a combination of a collaborative (adaptive) and command/control (hierarchical) approach for effective management.

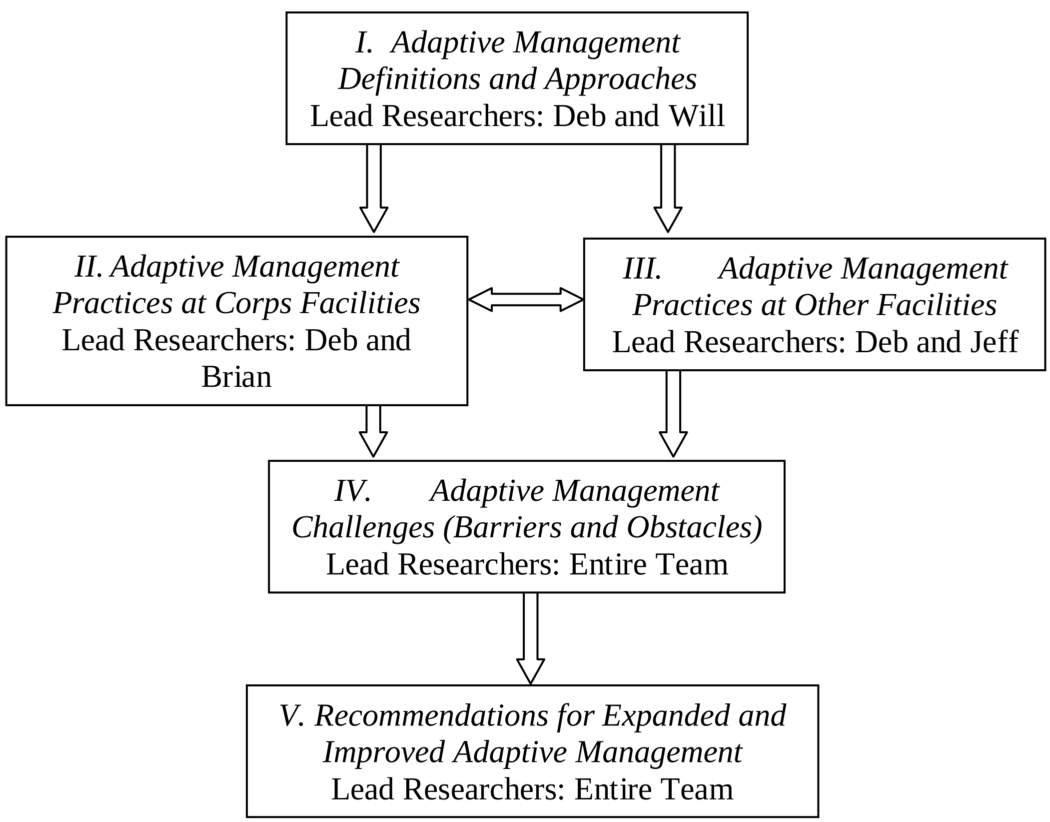
Most of the experience and experimentation in adaptive management has occurred in the natural resource and land management agencies of the federal bureaucracy. Koontz and Bodine (2008) in analyzing work within the U.S. Bureau of Land Management and the U.S.D.A. Forest Service point out that these agencies are challenged by the notion of adaptive management and that the idea of bottom-up organization is better for ecosystem management as it enables power sharing between all levels of the agency and that barriers to the enacting of adaptive management techniques stem from political, cultural, and legal traditions/policies. Gunderson and Light (2006) in their work on adaptive management in the Everglades ecosystem point out that adaptive governance works well to address complex, complicated environmental issues where many different stakeholder interests exist and that there is a difference between true adaptive management and "trial and error management"- adaptive management seeks to educate everyone on how to make the best decision, not just try things until something works. The Army Corps of Engineers has attempted adaptive management in selected sites (USACE 2007, USACE 2009), but there are still questions about implementation and true success of the projects.

Koontz (1997) highlights some of the differences between state and federal public forest management including barriers for federal agencies that keep them typically constrained by some combination of formalized planning documents, federal mandates, and various degrees of legislation. Servheen et al (1996) also indicate barriers at the federal level in terms of improved fish and wildlife management stating that in order for management to become more adaptive, the agencies must overcome the in place organizational characteristics and inertia of the bureaucracy.

Some authors have suggested avenues toward pursuing more efficient and effective governance in part through adaptive management techniques. Kettl (2002) proclaims that the transformation of governance is necessary but the bureaucracy wants to stick to the traditional hierarchical model. Presently, with the complexity of making policy decisions that model no longer works, especially when administrators are brought before Congress to take responsibility for decisions they don't really make or do not know enough about. Khademian (2009) in his work on financial regulatory reform goes so far as to say a spreading out of management to a variety of smaller agencies would help speed up decision making, and more collaboration is necessary to streamline decision making. Goldsmith and Eggers (2004) back up this idea by pointing out that the new shape of the public sector should include the network model of more small entities because it allows for more specialization (which is helped by collaboration of many different smaller, specialized groups), more innovation and more speed and flexibility in production and service delivery. The IRS has done a good job in achieving a widespread network of companies to help people file taxes online (increased reach to the public, faster, more flexible, innovation is important). Finally, Agranoff (2007) points out that most important to the success of government agencies is creating some kind of joint vertical and horizontal structure that encourages the most communication and coordination amongst the various members. The problem is, the way one manages a more vertical, hierarchical, formal structure is very different than how one manages a more horizontal, network-based, ad hoc structure, and these two kinds of management must be able to work together to create an effective and efficient system. Also, on some level, there needs to be an inner core of structured individuals with certain responsibilities to keep the organization pointed in the right direction, as well as "champions" of the cause to arouse interest and support. If a horizontal network gets too stretched out the response will not happen as efficiently as desired (especially in something like crisis management or terrorism response).

IV. Methods, Procedures, Facilities (to be used to evaluate technical adequacy)

Our overall research design can be visualized with the following diagram:



The four Investigators on this project will work in a coordinated fashion to achieve our objectives by taking the following steps.

Definitions and Approaches. We have reviewed the definitions of adaptive management that appear in the literature and in government practice, and have developed a clear and transparent yet robust definition. We have completed a further more intense review of the literature of adaptive management conceptually and how it is used in practice.

Adaptive management practices at USACE facilities. The IWR Project Manager will provide us with the facilities and projects where adaptive management has been used by USACE. We will follow up with personnel from those projects and facilities to determine what they did, how they did it, whether it was deemed successful, what were the unintended consequences and barriers, and how it the policy being changed or how should it be changed into the future (i.e. adapting adaptive management). For certain experienced or successful projects or facilities, we will choose one or two and do an on-site visit to obtain more in-depth information. An evaluative instrument for conducting these interviews is in draft form and is being refined.

Adaptive management practices at other federal/state facilities. A similar, parallel process with be followed for other state and federal agencies, but the time frame of this process precludes doing a thorough inventory. Using literature review and initial interviews, we will identify key agencies and projects that are actively using adaptive management, and then focus more in-depth on approximately 2 of these as case-studies. We will identify what they did, how they did it, whether it was deemed successful, what were the unintended consequences and barriers, and how it the policy being changed or how should it be changed into the future.

Adaptive management challenges: obstacles and barriers. We will synthesize the information we have obtained by our interviews and visits and look for common obstacles and barriers, and clear paths to success, for the use of adaptive management in water resources management and policy.

Recommendations for expanded and improved adaptive management. Our final report will provide all of the above information, but its main message and utility will be to provide recommendations for how adaptive management can best be incorporated into policy, what are the ways barriers can be overcome, and how the process itself can be improved. These recommendations will be directed at the USACE, but will be applicable to other agencies that utilize adaptive management for water resources decision-making.

V. Student Training

We have involved two graduate students in this project, one from the Water Resources Science graduate program at the Twin Cities campus of the University of Minnesota, and one from the graduate program at the Strom Thurmond Institute at Clemson University. These students have completed the literature reviews, have prepared the draft assessment instrument, and will assist in the interview process and the write-up of the final report. They will also assist with information transfer activities. These students are not only benefiting from learning the details, advantages, and disadvantages of adaptive management as it is practiced, but will have benefited from networking and interacting with federal and state agency water resource managers who are applying this technique on the ground (i.e. “real world” experience).

VI. Information Transfer Plan

Our information transfer plan includes our final report to IWR (ACE is our primary audience), which will be posted on the NIWR website once accepted by IWR. We will also present this report to the annual NIWR meeting in Washington, DC, in February of 2012, and encourage our network of directors to bring it to the attention of their stakeholders. We will prepare a paper based on the final report to be published in the peer-reviewed literature such as in *Policy Science*, *Integrated Environmental Assessment and Management*, or *Public Administration Review* (agency practitioners are the primary audience). We will also arrange to present our findings and recommendations to professionals at federal and state facilities via seminars and visits. For example, we will request to present our findings to the Midwest Natural Resources Group, a formal working group composed of the Regional Directors of all the Federal Agencies in the Midwest (USACE, USFWS, USFS, USGS, DOT, USPS, etc). Finally, we will present our findings at professional meetings that have considerable interest in the application of adaptive management, or those with significant government agency participation (e.g. Society of Environmental Toxicology and Chemistry; 1/3 of its membership and leadership is federal government managers and scientists).

There have been no publications or presentations to date. This project has not offered the opportunity for follow-on funding at this time.

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Information Transfer Program Introduction

We have not funded Information Transfer projects.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	2	0	1	0	3
Ph.D.	4	0	0	0	4
Post-Doc.	0	0	0	0	0
Total	8	0	1	0	9

Notable Awards and Achievements

Arnold, William: 2011 George W. Taylor Award for Distinguished Research, UMN College of Science and Engineering recognition of younger faculty members who have shown outstanding ability in research.

Bauer, Marvin: 2010 William T. Pecora Award presented by NASA & the US Department of the Interior, For recognition of his pioneering work in remote sensing of natural resources.

Brezonik, Patrick: 2010 Career Appreciation Award from the U.S. Environmental Protection Agency

Chiu, Yi-Wen, Ph.D. student: Runner-up Award for Poster Competition at the 2010 Gordon Research Conference: Industrial Design, for poster titled “Water Consumption by Energy Sector under Climate and Population Change Effects.”

Chraibi, Victoria, M.S. student: Fulbright Canada - RBC EcoLeadership Grant 2010-2011

Dietz, Robert, Ph.D. student: 2010 Geological Society of America Student Travel Grant

Dolph, Christine, Ph.D. student: EPA STAR Graduate Fellowship 2010-2011

Dolph, Christine, Ph.D. student: Graduate School Doctoral Dissertation Fellowship for 2010-2011

Dolph, Christine, Ph.D. student: Butler and Jessen Water Resources Science Fellowship for 2010.

Johnson, Thomas: 2011 Fellow of the American Geophysical Union (AGU). Fellows are limited to 0.1% of the membership.

Jones, Ajay, M.S. student: 2010 National Aquatic Plant Management Society 1st Place Poster Presentation
Kjerland, Tonya, M.S. student: Diversity of Views and Experiences (DOVE) Fellowship for the 2010-2011 academic year from the University of Minnesota Graduate School.

Knight, Joseph: 2011 College of Food and Natural Resources Sciences (CFANS) Distinguished Teaching Award - Undergraduate Faculty.

Liukkonen, Barb & Team: 2010 Association of Natural Resources Extension Professionals (ANREP) Bronze Award for team creation of the Watershed Game.

Louwsma, Jane, M.S. student: University of Minnesota Graduate School Fellowship 2010-2011.

Newman, Raymond: 2011 University of Minnesota Distinguished Teaching Award - Outstanding Contributions to Post baccalaureate, Graduate, and Professionalism.

Oster, Ryan, M.S. student: 2010 Sigma Xi Scientific Research Society Grant to support thesis research.

Paola, Chris: 2011 Lyell Medal from the Geological Society of London for significant contribution to the science by means of a substantial body of research.

Perry, Jim: 2011 College of Food and Natural Resources Sciences (CFANS) Student Board Outstanding Professor Award.

Saar, Martin: University of Minnesota College of Science & Engineering's 2011 George W. Taylor Career Development Award. Recognizes exceptional contributions to teaching by a candidate for tenure.

Swackhamer, Deborah: Society of Environmental Toxicology and Chemistry (SETAC) 2009 Founders Award. Recognizes outstanding career accomplishments that promote research, education, communication & training in the environmental sciences. Swackhamer, Deborah: Ada Comstock Distinguished Women Award 2010. Recognizes leadership and scholarly achievement of the University's tenured female faculty.

Tsui, Martin, Ph.D. student: University of Minnesota Graduate School Doctoral Dissertation Fellowship for 2010-2011.

Were, Valerie: Compton International Fellowship 2010-2011 from Interdisciplinary Center for the Study of Global Change (ICGC). Provides research support to graduate students from sub-Saharan Africa or Latin American whose studies & research will address issues of peace, human security & conflict resolution in relation to population & environmental concerns.

Wilson, Bruce: 2010 CFANS Distinguished Graduate Teaching Award.

Wilson, Melissa, Ph.D. student: 2010 International Plant Nutrition Scholar Award. Recognizes graduate students internationally for outstanding research.

Woltering, Martijn, Ph.D. student: University of Minnesota Graduate School Doctoral Dissertation Fellowship for 2010-2011

Yi-Wen Chiu, Ph.D. student: 2010 Conference Scholarship from International Society of Industrial Ecology.

Zigah, Prosper, Ph.D. student: 2010 National Ocean Sciences Mass Spectrometry Graduate Fellowship from the Woods Hole Oceanographic Institution.

Conferences, Short Courses, Seminars The Water Resources Center sponsored or cosponsored conferences or other informational programs with these names:

• The annual Minnesota Water Resources Conference was held October 19-20, 2010 with over 600 participants. Co-sponsors were the UM Department of Civil Engineering, the Minnesota Section of American Society of Civil Engineers, the MN Sea Grant Program, and the Center for Water and Environment at UM Duluth. The conference facilitated interaction among water resources professionals including resource managers; researchers; local, state, and federal agency staff; consultants and practicing engineers; and students in the field.

• The 4th Annual Minnesota Wetlands Conference, hosted by the MN Wetland Delineator Certification Program and the MN Wetland Professionals Association, was held January 19, 2011. This conference focused on the three parameters of wetland identification, featuring some of the less-commonly seen topics. . This is an excellent opportunity for working professionals, researchers, students, scientists, consultants, regulators, and wetland enthusiasts to come together and share their wetland knowledge.

• The Minnesota Wetland Delineator Certification Program hosted 11 training workshops across Minnesota, with a total of 160 attendees. The University of Minnesota's Wetland Delineator Certification Program (WDCP) delivers cutting-edge content featuring the know-how of the region's top wetland, soil, vegetation and water experts. Wetland delineator certification adds credibility and customer confidence to a variety of wetland-related professions by formally recognizing the training and expertise that goes into delineation. Re-certification keeps you up-to-date on changing requirements and technologies in the field.

• Clean Water and Climate Adaptation Summit 2010. September 16 and 17, 2010. 250 people attended. At the University of Minnesota Landscape Arboretum, a conference on Green Infrastructure and Climate Adaptation. The conference goal was to bring together local government officials and staff, industry leaders, natural resource professionals, researchers, and citizens to learn how climate trends might affect Minnesota and the region, how green infrastructure will be a key water-manage¬ment strategy, and how to make informed decisions and enhance the economic viabil¬ity of their communities.

• The Water Resources Center administers the Onsite Sewage Treatment Program (OSTP). This partnership between the Minnesota Pollution Control Agency and the College of Food, Agriculture, and Natural Resources Science provides training to those that design, install, inspect or take care of septic systems in Minnesota. Between 3/1/2010 and 2/28/11, this program conducted 65 workshops across the state with 2445 attendees. The OSTP also educates septic system owners, community leaders, and real estate agents in addition to conducting research and providing technical assistance.

• Brezonik-Semmens Environmental Engineering Symposium Sept. 24, 2010 The Department of Civil Engineering presented a symposium honoring the careers of environmental engineering professors Pat Brezonik and Mike Semmens held Friday, Sept. 24, 2010. This all-day event featured presentations on topics including environmental chemistry and membranes for water and wastewater treatment from top researchers in the U.S. and abroad. The Water Resources Center was a co-sponsor.

• People and Water in the Mekong River Basin. May 1, 2010, 2B Hmoob Summit, University of Minnesota, Saint Paul. This workshop was organized by the Hmong Student Association, and the presentation was attended by about 60 participants.

• KAP focus Group Workshop. Full-day workshop organized and facilitated by Karlyn Eckman for about ten staff of state and local governments implementing NPS projects, May 24, 2010, University of Minnesota, Saint Paul.

• Evaluating the Social Outcomes of Water Quality Projects. Video-conference presentation on August 23, 2010, for the Buffalo-Red River Water Quality Team. Approximately 20 individuals from state and local governments participated.

• KAP Study Workshop. Training workshop organized on September 13, 2010, at Minnesota Sea Grant, Duluth, for the Conservation Corps of Minnesota. A six-member crew of survey enumerators was trained in this full-day workshop.

• Evaluating Outcomes of Water Resources Projects on Target Audiences. Presentation on October 13, 2010, for the Watershed Partners meeting at Capitol Region Watershed District, Saint Paul. About 50 people attended this meeting.

• The Application of Knowledge, Attitudes and Practices (KAP) Studies in Human Resources. Karlyn Eckman and Kseniya Voznyuk, February 2, 2011, at Saint Mary's University, Minneapolis. Approximately 25 students attended this session.

• 319 project Maximizing the economic benefits of manure to reduce nutrient loading, Jose Hernandez and local workshop hosts conducted 14 small-group workshops on optimizing methods for manure application, for 121 livestock producers and their agricultural professionals, in the March 2010-Feb 2011 period. Six workshop presentations were given for 295 commercial animal waste technicians on the same topic.

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 10/20/10 annual Water Resources Conference, St Paul, MN, 90 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 10/22/10 Water Sustainability Roundtable, invited speaker, Navarre, MN, 50 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/17/10 Minnesota Environmental Initiative – Water Sustainability, St Paul, MN, 300 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 12/06/10 Minnesota Association of Soil and Water Conservation Districts annual meeting, plenary speaker, St Paul, MN, 300 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 1/5/11 Minnesota House of Representatives Environment and Natural Resources Committee, St Paul, MN, 60 people plus committee members

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 1/22/11 League of Women Voters, Minnetonka, MN, 50 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 2/3/11 Minnesota Drainage Control annual conference, plenary speaker, St Cloud, MN, 120 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 2/8/11 Minnesota Senate Joint Committee Hearing, Environment and Natural Resource Committee and Agriculture Committee, St Paul, MN, 90 people plus committee members

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 2/9/11 Minnesota Pollution Control Agency annual interagency Water and Watersheds meeting, invited speaker, St Paul, MN, 80 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 2/22/11 Minnesota Pollution Control Agency Citizen Board, invited speaker, St Paul, MN, 20 people plus board members

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 3/3/11 Minnesota Erosion Control Association annual conference, plenary speaker, Plymouth, MN, 150 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 5/4/11 Minnesota Groundwater Association, plenary speaker, St Paul, MN, 250 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 5/6/11 College of Food, Agriculture, and Natural Resource Sciences, University of Minnesota, St Paul, invited speaker at symposium on Agriculture and Water in the 21st Century, 300 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 6/15/11 National ABC, invited speaker, Bloomington, MN, 100 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” Other assorted Framework presentations (7) – about 200 people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 9/10 Environmental Quality Board, 20 Agency commissioners and audience members

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 9/10 Brown bag lunch at Emmons and Olivier Resources, 15 Water and land resource professionals

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 10/10 Brainerd morning and noon Rotary Clubs, 95 Business people

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 10/10 US EPA Water Roundtable at Freshwater Society, 60 Water resource professionals and others

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 10/10 MPCA Stormwater Steering Committee, 25 Stormwater management professionals

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 10/10 Red River Basin Manager’s Team, 12 Water resources professionals

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/10 WaterShed Partners Water Education Summit, 15 Water educators and others

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/10 Minneapolis area Water Advisory Board, 15 Drinking water utility managers and elected officials

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/10 Shoreview Green Communities Group, 20 Citizens

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/10 Conference on the Environment co-sponsored by Central States Water Environment Association and Air & Waste Management Association, 150 Environmental engineering professionals

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/10 Clean Water Council, 20 CWC members and observers

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/10 NPS Mississippi River Forum – Minneapolis and St. Cloud, 68 Active citizens, local government officials, environmental professionals

• “Minnesota Water Sustainability Framework: Looking Far into the Future” 11/10 Water Resources Seminar, 50 UM Scientists, staff, and other interested individuals

• “Minnesota Water Sustainability Framework: Looking Far into the Future” Deb Swackhamer also has conducted multiple briefings of the Framework with the Commissioners of MPCA, DNR, MDH, and MDA and with staff of most of the Minnesota Congressional delegation.

Publications from Prior Years

1. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B.J. 2008. Climate Change as a Factor in Export of Dissolved Organic Matter from Agricultural Watersheds. Oral presentation in symposium titled “Global Climate Change and Agriculture: Interactions, Land-Use Patterns, and Educational Connections” at the 93rd annual meeting of the Ecological Society of America. August 3-8, 2008. Milwaukee, WI.
2. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B. J., J. Y. King, D. J. Mulla, J. C. Finlay, and G. R. Sands. 2008. The Influence of Landscape Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems. Oral presentation given at the annual fall meeting of the American Geophysical Union. December 2008. San Francisco, CA.
3. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B. J. 2008. Effects of Landscape Drainage on Dissolved Carbon Export. Presentation given at the Minnesota/Iowa Drainage Research Forum. December 2008. Owatonna, MN.
4. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Results from this research were also incorporated into lecture materials on global carbon cycling and impacts of land use change for a class on “Biogeochemical Processes” (EEB 4611) University of Minnesota – Spring Semester, 2008.
5. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Preliminary results from this research have also been presented in smaller group discussion sessions in the Departments of Soil, Water, and Climate and Ecology, Evolution, and Behavior at the University of Minnesota.
6. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Other Publications - Steen, P.O.; Grandbois, M., McNeill, K.; Arnold, W.A. 2009. Photochemical Formation of Halogenated Dioxins from Hydroxylated Polybrominated Diphenyl Ethers (OH-PBDEs) and Chlorinated Derivatives (OH-PBCDEs). Environmental Science and Technology. accepted.
7. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Other Publications - Buth, J.M., Grandbois, M., Vikesland, P.J., McNeill, K., Arnold, W.A. 2009. Aquatic Photochemistry of Chlorinated Triclosan Derivatives: Potential Source of Polychlorodibenzo-p-dioxins. Environmental Toxicology and Chemistry. accepted.
8. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Book Chapters - Arnold, W.A., and K. McNeill. “Abiotic Degradation of Pharmaceuticals: Photolysis and Other Processes” to appear in Analysis, Fate And Removal Of Pharmaceuticals In The Water Cycle Eds. M. Petrovic and D. Barcelo, 2007.
9. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Arnold, W.A., 2007. Solar Photochemistry of Pharmaceutical Compounds. American Water Works Association Water Quality Technology Conference, Advanced Oxidation Technologies in Water Treatment: Fundamentals and Applications Workshop, November 4, 2007.
10. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - McNeill, K., 2009. Incineration or Liquid Handsoap: Which is the Larger Source of Dioxins to the Aquatic Environment? College of St. Catherine, St. Paul, MN.
11. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - McNeill, K., 2009. Incineration or Liquid Handsoap: Which is the Larger Source of Dioxins to the Aquatic Environment? Gustavus Adolphus College, St. Peter, MN.
12. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Buth, J.M., W. A. Arnold, and K. McNeill. 2008. Photochemical Fate of

Chlorinated Triclosan Derivatives. Poster. Gordon Research Conference, Environmental Sciences: Water, Holderness, NH.

13. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Steen, P.O., M. Grandbois, W.A. Arnold, and K. McNeill. 2008. Hydroxylated Polybrominated Diphenyl Ether Photolysis Quantum Yields and Product Identification. Environ. Chem. Div., American Chemical Society National Meeting, Philadelphia, PA, 48(2), 608-611.
14. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Steen, P.O., M. Grandbois, W. A. Arnold, and K. McNeill. 2008. Hydroxylated Polybrominated Diphenyl Ether Photolysis: Quantum Yields and Product Identification. Minnesota Water Conference, St. Paul, MN.
15. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Steen, P.O.,M. Grandbois, K. McNeill, and W. A. Arnold. 2009. Photolysis of Hydroxylated Polybrominated Diphenyl Ethers. Micropol & Ecohazard 2009. 6th IWA/GRA Specialized Conference on Assessment and Control of Micropollutants/Hazardous Substances in Water, San Francisco, CA.
16. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Buth, J.M., W. A. Arnold, and K. McNeill. 2009. Formation and Occurrence of Chlorinated Triclosan Derivatives (CTDs) and their Dioxin Photoproducts. Micropol & Ecohazard 2009. 6th IWA/GRA Specialized Conference on Assessment and Control of Micropollutants/Hazardous Substances in Water, San Francisco, CA.
17. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Dissertations - Jeremiah, J. M.S. Thesis, University of Minnesota, Department of Civil Engineering. Stream Water Quality Monitoring using Wireless Embedded Sensor Networks. 2007.
18. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Henjum, M.B., C. R. Wennen, M. Hondzo, R. M. Hozalski, P. J. Novak, and W. A. Arnold. 2009. Linking Near Real-Time Water Quality Measurements to Fecal Coliforms and Trace Organic Pollutants in Urban Streams, 2009 Joint Assembly (AGU), Toronto, CA, 2009.
19. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Kang, J.M., S. Shekhar, M. Henjum, P. Novak, and W.A. Arnold. 2009. Discovering Teleconnected Flow Anomalies: a Relationship Analysis of Dynamic Neighborhoods (RAD) Approach. 11th International Symposium on Spatial and Temporal Databases, Aalborg, Denmark accepted. (peer-reviewed)
20. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Kang, J.M., S. Shekhar, C. Wennen, and P. Novak. 2008. Discovering Flow Anomalies: A SWEET Approach. In: IEEE International Conference on Data Mining. (2008) 851–856. (peer-reviewed)
21. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Arnold, W.A. 2009. The WATERs Project: Wireless Sensor Technologies for Urban Water Quality Management, Urban Ecosystems Seminar Series, University of Minnesota, St. Paul, MN, 2009
22. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Novak, P.J. 2009. Sensor Networks for Urban Water Quality Monitoring. Environmental Sciences: Water Gordon Research Conference, Plymouth, NH, 2009.
23. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Wennen, C.R., M. B. Henjum, R. M. Hozalski, P. J. Novak, and W. A. Arnold. 2008. Application of Wireless and Sensor Technologies for Urban Water Quality Management: Pollutant Loading in Stormwater Ponds. Minnesota Water Conference, 2008,

St. Paul, MN.

24. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Henjum, M., C. Wennen, M. Hondzo, R. M. Hozalski, P. J. Novak, and W. A. Arnold. 2008. Application of Wireless and Sensor Technologies for Urban Water Quality Management: Pollutant Detection in Urban Streams. Minnesota Water Conference, 2008, St. Paul, MN.
25. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Novak, P., J. Jazdzewski, S. Kim, W. Arnold, R. Hozalski, and M. Hondzo. 2007. Wireless Technologies and Embedded Networked Sensing for Urban Water Quality Management. Presentation at the Association of Environmental Engineering and Science Professors Education and Research Conference, Blacksburg, Virginia, July 2007.
26. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Hozalski, R., S. Kim, J. Jazdzewski, M. Hondzo, P. Novak, and W. Arnold. 2007. Wireless Technologies and Embedded Networked Sensing: Application to Integrated Urban Water Quality Management, World Environmental and Water Resources Congress 2007, May 15-18, Tampa, FL.
27. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Hondzo, M. ,W. A. Arnold, R. M. Hozalski, P. J. Novak, and P. D. Capel. 2006. Wireless Technologies and Embedded Network Sensing: Options for Environmental Field Facilities. Presented at International Research and Education Planning Visit: Cyberinfrastructure based water research: towards the next generation of environmental observatories. August 31-Sept 1 Delft, The Netherlands and Sept. 2-3, Newcastle upon Tyne (UK), 2006.
28. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Arnold, W.A., R. M. Hozalski, M. Hondzo, P. J. Novak, and P. D. Capel. 2006. Wireless Technologies and Embedded Network Sensing: Options for Environmental Field Facilities.. Presented at CLEANER Planning Grant PI meeting, March 2006, Arlington, VA
29. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Kim, S.-C., M. Hondzo, R. M. Hozalski, P. Novak, W. Arnold, J. D. Jazdzewski, N. Jindal, and P. D. Capel. 2006. Integrated Urban Water Quality Management: Wireless Technologies and Embedded Networked Sensing. Poster presented at the American Geophysical Union National Meeting, San Francisco, CA. December 2006.
30. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Jazdzewski, J.D., M. Hondzo, and W. A. Arnold. 2006. Stream Water Quality Monitoring Using Wireless Embedded Sensor Networks. Poster presented at the Minnesota Water 2006 and Annual Water Resources Joint Conference, Brooklyn Center, MN, October 24-25, 2006.
31. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - Steiger-Meister, K. 2009. The Drama of the Commons and Its Impact on Adaptive Management. conference proceeding paper, American Water Resource Association Specialty Conference: Adaptive Management of Water Resources II, Snowbird, UT. (6/09) In review
32. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - Steiger-Meister, K., and D. R. Becker. Connecting Environmental Policy with Citizen Engagement: A Comparative Study between Minnesota’s Lake Improvement Districts and Wisconsin’s Lake Districts. Manuscript in preparation for Journal of the American Water Resources Association.
33. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - Steiger-Meister, K., and D. R. Becker. Citizen Stewardship of Water Resources: A Look at How Water Policy can Create and Coordinate Citizen Action in Minnesota for Environmental Change. Manuscript in preparation for

Water Policy.

34. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2008. When Ripples Become Waves: Building Synergy Among Local Stakeholders to Affect Top-down Water Policy. Presented at the 14th International Symposium on Society and Resource Management (ISSRM) on June 13, 2008, University of Vermont in Burlington, VT.
35. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2009. Minnesota's Lake Improvement Districts. Panelist at the Lakes and Rivers Conference hosted by Minnesota Waters, Rochester, MN. (5/2009) Abstract accepted
36. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2009. The Drama of the Commons and Its Impact on Adaptive Management. American Water Resource Association Specialty Conference: Adaptive Management of Water Resources II, Snowbird, UT. (6/2009) Abstract accepted.
37. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2009. Connecting Environmental Policy with Citizen Engagement: A Comparative Study between Minnesota's Lake Improvement Districts and Wisconsin's Lake Districts. Minnesota Water Resources Conference, University of Minnesota in Saint Paul, MN. (10/2009) Abstract in review.
38. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - Orr, C. H., A. F. Lightbody, and R. Bronk. 2009. Determination of the Short-term Response of Aquatic Macroinvertebrate Communities to Suspended Sediment Loading. North American Benthological Society Annual Meeting, May 17-22, Grand Rapids, MI.
39. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - Lightbody, A., P. Belmont, J. Marr, C. Orr, and C. Paola. 2008. Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads. Water Resources Conference, St. Paul, MN, October 27, 2008.
40. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - J. Sayers. 2009. Outdoor StreamLab—From Construction Phase to Research Phase. St. Cloud State University Research Seminar, St. Cloud, MN.
41. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - J. Sayers. 2009. Outdoor StreamLab--from Construction Phase to Research Phase, Including Determination of Groundwater Flow with In-bank Flood Simulations. Poster presentation: NorthStar STEM Alliance Student Research Symposium, University of Minnesota Bell Museum of Natural History
42. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - J. Sayers. 2009. Outdoor StreamLab--from Construction Phase to Research Phase, Including Determination of Groundwater Flow with In-bank Flood Simulations. American Indian Science and Engineering Society (AISES) Region 5 meeting.
43. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Other Publications - Weiss, P., G. LeFevre, and J. Gulliver. 2008. Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices: A Literature Review. University of Minnesota, St. Anthony Falls Laboratory Project Report No.515.
44. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Other Publications - Hozalski, R.,G. LeFevre, and J. Gulliver. 2009. Assessment of the Stormwater Infiltration and Pollutant Removal Capacities of Rain Gardens. Proceedings to EWRI/ASCE Thailand 09: An International Perspective on Environmental and Water

Resources.

45. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Conference Proceedings - Lefevre, G., and Almer. 2009. Minnesota Ground Water Association Conference: Impacts of Stormwater Infiltration on the Groundwater System.
46. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Conference Proceedings - Levevre, G., P. Novak and R. Hozalski. Petrochemical Runoff into Raingarden Soils—Remediation or Residuals. 23nd Annual Conference on the Environment: Water Environment Association, Air & Waste Management Association, Minneapolis, MN.
47. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Book Chapters - Arnold, W.A., and K. McNeill. 2007. Transformation of Pharmaceuticals in the Environment: Photolysis and Other Abiotic Processes In M. Petrovic and D. Barcelo, Eds. Analysis, Fate and Removal of Pharmaceuticals in the Water Cycle, Volume 50. Amsterdam, Netherlands, Elsevier Science. 600 pp.
48. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Arnold, W.A. 2007. Solar Photochemistry of Pharmaceutical Compounds. American Water Works Association Water Quality Technology Conference, Advanced Oxidation Technologies in Water Treatment: Fundamentals and Applications Workshop, November 4, 2007.
49. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Buth, J., W. A. Arnold, and K. McNeill. 2008. Photochemical Fate of Chlorinated Triclosan Derivatives. Poster. Gordon Research Conference, Environmental Sciences: Water, Holderness, NH, June, 2008.
50. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B.J. 2008. Climate Change as a Factor in Export of Dissolved Organic Matter from Agricultural Watersheds. Oral presentation in symposium titled “Global Climate Change and Agriculture: Interactions, Land-Use Patterns, and Educational Connections” at the 93rd annual meeting of the Ecological Society of America. August 3-8, 2008. Milwaukee, WI.
51. 2006MN155B ("Ecological Stoichiometry and Microbial Biodiversity Effects on Water Quality in Minnesota Lakes") - Conference Proceedings - • Scott, J.T., T. LaPara and J.B. Cotner. 2008. Biological Stoichiometry of Prokaryotic Heterotrophs: Implications for Nutrient Recycling and Ecosystem Production. North American Benthological Society Annual Meeting, 25-30 May 2008, Salt Lake City, Utah.
52. 2006MN155B ("Ecological Stoichiometry and Microbial Biodiversity Effects on Water Quality in Minnesota Lakes") - Conference Proceedings - • LaPara, T.M., K. Holzmiller, A. Ling, M. Funke, K. Hope, J.T. Scott, and J.B. Cotner. 2008. If ‘Everything Is Everywhere’, then Nature Must Be Selecting Really, Really Hard! Poster presentation at the 108th General Meeting of the American Society for Microbiology
53. 2006MN155B ("Ecological Stoichiometry and Microbial Biodiversity Effects on Water Quality in Minnesota Lakes") - Conference Proceedings - • Funke, M., A. Ling, K. Holzmiller, K. Hope, J.T. Scott, T. LaPara, and J. Cotner. 2008. Bacterial Diversity and Nutrients in Urban Lakes: Are They Related? Poster presentation at the 108th General Meeting of the American Society for Microbiology
54. 2006MN155B ("Ecological Stoichiometry and Microbial Biodiversity Effects on Water Quality in Minnesota Lakes") - Conference Proceedings - • Ling, A., K. Holzmiller, and T.M. LaPara. 2008. Resolving Sample Bias When Using Automated Ribosomal Intergenic Spacer Analysis (ARISA) to Characterize Bacterial Community Composition. Poster presentation at the 108th General Meeting of the American Society for Microbiology
55. 2006MN155B ("Ecological Stoichiometry and Microbial Biodiversity Effects on Water Quality in Minnesota Lakes") - Conference Proceedings - • Ling, A., K. Holzmiller, and T.M. LaPara. 2007. Resolving Sample Bias When Using ARISA to Characterize Bacterial Community Composition. Oral

presentation at the annual meeting of the North-Central Branch of the American Society for Microbiology

56. 2006MN155B ("Ecological Stoichiometry and Microbial Biodiversity Effects on Water Quality in Minnesota Lakes") - Conference Proceedings - • Cotner, J.B. 2007. The Microbial Role in Littoral Zone Biogeochemical Processes: Why Wetzel was Right. Special symposium to honor Robert G. Wetzel. SIL, Montreal, Canada, Aug, 2007.
57. 2006MN155B ("Ecological Stoichiometry and Microbial Biodiversity Effects on Water Quality in Minnesota Lakes") - Conference Proceedings - • Cotner, J.B., T. LaPara, A. Amado, M. Funke, and A. Wiley. 2007. Bacterial Diversity and Its Effects on Nutrient and Carbon Cycling in Lakes. American Museum of Natural History Conference on Microbial Conservation.
58. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Dissertations - Jeremiah, J., M.S. Thesis, University of Minnesota, Department of Civil Engineering. Stream Water Quality Monitoring Using Wireless Embedded Sensor Networks. 2007.
59. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Novak, P., J. Jazdzewski, S. Kim, W. Arnold, R. Hozalski, and M. Hondzo. 2007. Wireless Technologies and Embedded Networked Sensing for Urban Water Quality Management. Presentation at the Association of Environmental Engineering and Science Professors Education and Research Conference, Blacksburg, Virginia, July 2007.
60. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Hozalski, K.,J. Jazdzewski, M. Hondzo, P. Novak, and W. A. Arnold. 2007.'Wireless Technologies and Embedded Networked Sensing: Application to Integrated Urban Water Quality Management, World Environmental and Water Resources Congress 2007, May 15-18, Tampa, FL.
61. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Hondzo, M., W. A. Arnold, R. M. Hozalski, P. J. Novak, and P. D. Capel. 2006. Wireless Technologies and Embedded Network Sensing: Options for Environmental Field Facilities. Presented at International Research and Education Planning Visit: Cyberinfrastructure-based Water Research: Towards the Next Generation of Environmental Observatories. August 31-Sept 1 Delft, The Netherlands and Sept. 2-3, Newcastle upon Tyne (UK), 2006.
62. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Arnold, W.A., R. M. Hozalski, M. Hondzo, P. J. Novak, and P. D. Capel. 2006. Wireless Technologies and Embedded Network Sensing: Options for Environmental Field Facilities. Presented at CLEANER Planning Grant PI meeting, March 2006, Arlington, VA
63. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Kim, S.-C., M. Hondzo,R. M. Hozalski, P. Novak, W. A. Arnold, J. D. Jazdzewski, N. Jindal, and P. D. Capel. 2006. Integrated Urban Water Quality Management: Wireless Technologies and Embedded Networked Sensing. Poster presented at the American Geophysical Union National Meeting, San Francisco, CA. December 2006.
64. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Jazdzewski, J.D., M. Hondzo, and W. A. Arnold. 2006. Stream Water Quality Monitoring Using Wireless Embedded Sensor Networks. Poster presented at the Minnesota Water 2006 and Annual Water Resources Joint Conference, Brooklyn Center, MN, October 24-25, 2006.
65. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2008. When Ripples Become Waves: Building Synergy Among Local Stakeholders to Affect Top-down Water Policy. 14th International Symposium on Society and Resource Management (ISSRM) on June 13, 2008 at the University of Vermont in Burlington, VT.

66. 2006MN161B ("Development of a DNA Marker Gene System to Determine Sources of Fecal E. coli in Watersheds") - Other Publications - Yan, T., M. Hamilton, and M. J. Sadowsky. 2007. High Throughput and Quantitative Procedure for Determining Sources of Escherichia coli in Waterways Using Host-specific DNA Marker Genes. Applied Environmental Microbiology. 73:890–896.
67. 2006MN161B ("Development of a DNA Marker Gene System to Determine Sources of Fecal E. coli in Watersheds") - Conference Proceedings - Sadowsky, M. J. 2008. Microbial Source Tracking Methods: Myths and Realities Minnesota Pollution Control Agency, St. Paul, MN
68. 2006MN161B ("Development of a DNA Marker Gene System to Determine Sources of Fecal E. coli in Watersheds") - Conference Proceedings - Sadowsky, M. J. 2007. Development and Use of Marker Genes to Determine Sources and Sinks of Fecal Bacteria and Pathogens in the Environment. University of Montana Missoula, MT
69. 2006MN161B ("Development of a DNA Marker Gene System to Determine Sources of Fecal E. coli in Watersheds") - Conference Proceedings - Sadowsky, M. J. 2007. Library-Dependent Genotypic Methods for MST Studies. EpiNet, Chicago, IL.
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